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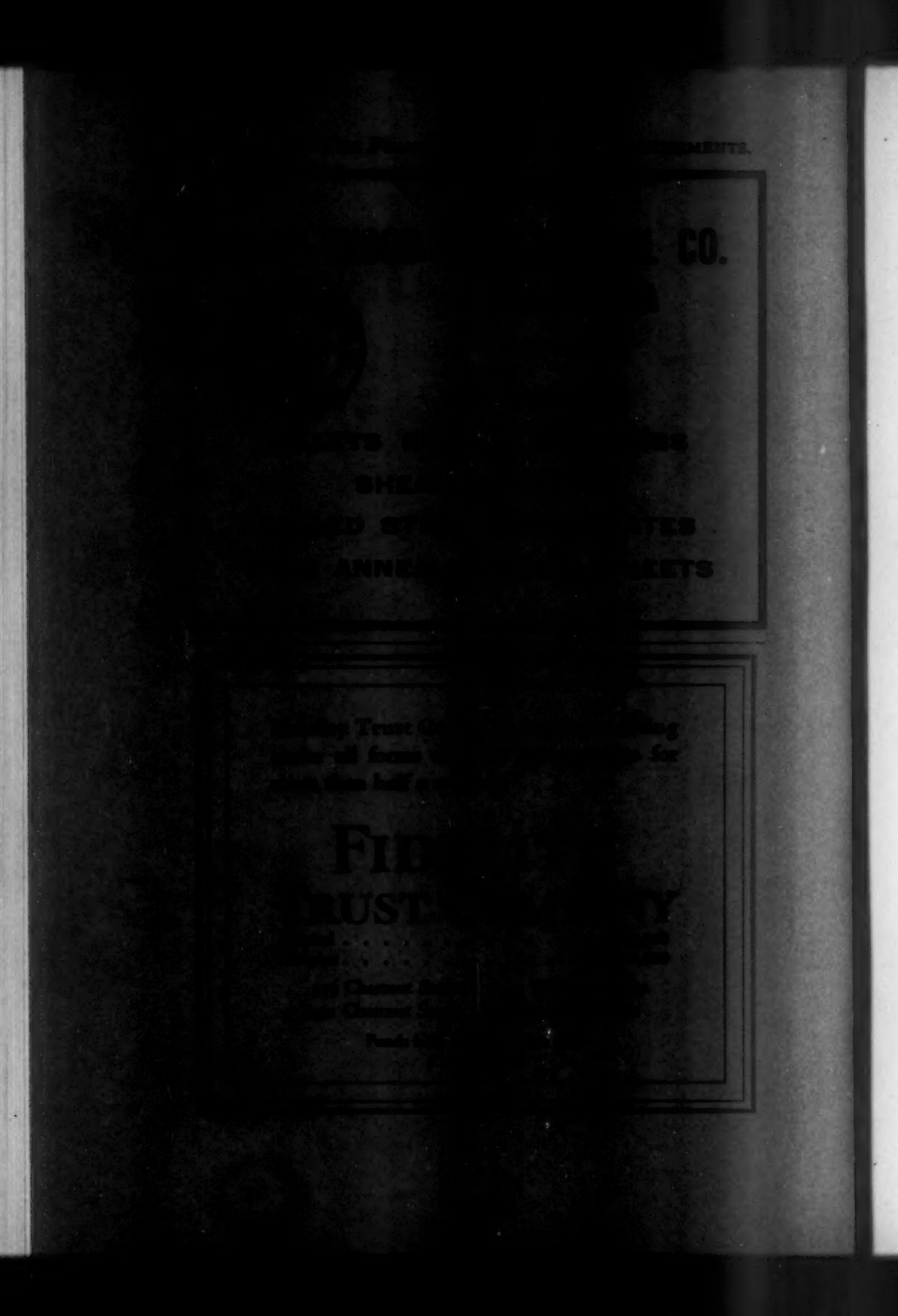

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LIGHTNING.*

BY

F. W. PEEK, Jr., M.E.E.

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IT IS the purpose of this paper to give as close an approximation as available data permit of the voltage and characteristics of lightning, as well as the effects of lightning on transmission lines, line insulation, lightning rods, etc. A knowledge of the general types of disturbances and their order of magnitude should be of value in determining the best means of protecting against them.

Many observations of lightning disturbances have been made on transmission lines. Since these disturbances bear a definite relation to the lightning stroke, they afford a very good source of information. In addition to field work, recent laboratory work with the lightning generator will be included. This generator has already been described in detail.[1] The laboratory observations include a study on model transmission lines with and without a ground wire, lightning rods, buildings, etc.

* Address delivered Thursday, September 18, 1924, on the occasion of the celebration of the centenary of the founding of The Franklin Institute.

[1] F. W. Peek, Jr.: "High Voltage Phenomena," JOUR. FRANK. INST., Jan., 1924. "Effect of Transient Voltages on Dielectrics," *A.I.E.E.*, Vol. xxxiv, p. 1857.

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THE VOLTAGE OF LIGHTNING.

In a lecture before this Institute last November, the author gave the results of laboratory measurements of sparking distances up to about 2,000,000 volts maximum.[2]

It was shown that about 150,000 volts maximum are required for every foot of spark. While this rule was found to apply up to the highest laboratory voltage, it, in itself, gave no assurance that it would apply indefinitely so that the voltage of lightning could be found by multiplying the length of the flash by this factor.

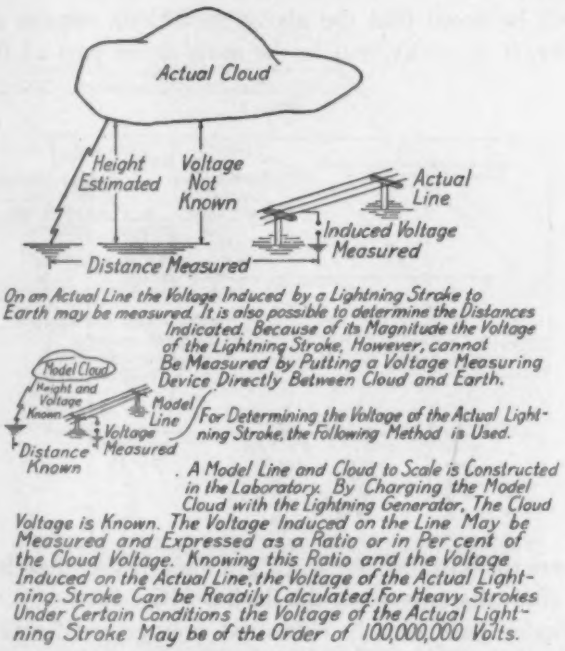
However, in the lecture referred to, an experiment was described which seems to offer an almost direct means of measuring lightning voltages. A short description of this experiment will be repeated here. When a lightning flash occurs within a certain distance of a transmission line, a certain percentage of the voltage of the bolt is induced on the line. The voltage of the bolt cannot be measured, but its distance from the line and height of cloud can be estimated. The actual voltage induced on the line can be measured by gaps or estimated from insulation flash-overs. The author has measured lightning voltages on transmission lines in Colorado as high as 500,000; insulator flash-overs by lightning have occasionally indicated voltages as high as 1,500,000 or more.

A model was made to scale representing cloud and transmission line for a certain observed condition. By means of the lightning generator, it was found that when a flash occurred from this model cloud, 1 per cent. of its voltage was induced on the model line. But it is known by observation that the voltage induced on an actual line, under similar conditions, is sometimes of the order of 1,000,000. If this is 1 per cent. of the voltage of an actual lightning flash, the voltage of the flash must be 100,000,000 volts (Fig. 1). This gives a voltage of 100,000 per foot of spark (330 kv/m.) which, considering the possible error, indicates that the needle gap spark curve may hold even at these extreme voltages. In fact, a value somewhat lower than the 150,000 volts per foot (495 kv/m.) of the laboratory would be expected, since the flash starts at the low air density of the high altitudes. It has been the opinion of many observers that

[2] F. W. Peek, Jr.: "High Voltage Phenomena," JOUR. FRANK. INST., Jan., 1924. "Tests at 1,000,000 Volts," *Elec. World*, Dec. 31, 1921.

the voltage of lightning is relatively low or that the flash, once started, would extend great distances at low voltages by some progressive action. Progressive action is readily understood where the spark takes place over a series of clouds by a multigap action and can, in fact, be shown in the laboratory. When the flash is from cloud to ground or from one cloud to another

FIG. 1.


Actual Cloud
Height Estimated
Voltage Not Known
Actual Line
Induced Voltage Measured
Distance Measured
On an Actual Line the Voltage Induced by a Lightning Stroke to Earth may be measured. It is also possible to determine the Distances Indicated. Because of its Magnitude the Voltage of the Lightning Stroke, However, cannot Be Measured by Putting a Voltage Measuring Device Directly Between Cloud and Earth.
Model Cloud
Height and Voltage Known
Model Line
Voltage Measured
Distance Known
For Determining the Voltage of the Actual Lightning Stroke, the Following Method is Used.
A Model Line and Cloud to Scale is Constructed in the Laboratory. By Charging the Model Cloud with the Lightning Generator, The Cloud Voltage is Known. The Voltage Induced on the Line May be Measured and Expressed as a Ratio or in Per cent of the Cloud Voltage. Knowing this Ratio and the Voltage Induced on the Actual Line, the Voltage of the Actual Lightning Stroke Can be Readily Calculated. For Heavy Strokes Under Certain Conditions the Voltage of the Actual Lightning Stroke May be of the Order of 100,000,000 Volts.

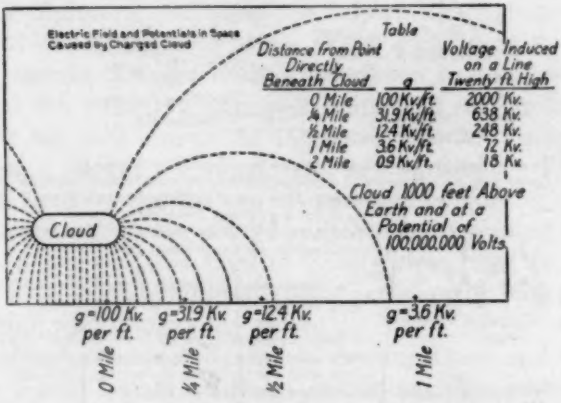
Method of measuring the voltage of an actual lightning stroke.

through clear air, as is usual with lightning, it is not clear how progressive action can occur. While the field produced by the charge is fairly uniform, it is probable that, at the instant before spark-over, a needle-like streamer forms and breakdown then corresponds to the needle gap distance. Needle gap spark-over requires less than 20 per cent. of the 30 kv/cm. required for uniform field. The sparking distance should usually correspond to a continuous voltage because there is generally no large transient until after the spark starts.

It thus appears, by approximately direct measurement, that the order of voltage of a severe lightning stroke to ground may be about 100,000,000. The lightning voltage during a storm will, of course, vary over a very wide range, sometimes much higher, but generally lower, than the value above. It has been observed that during a severe thunderstorm there may be many induced strokes at very low voltages, a less number at moderate voltages and so on to very few at the extreme voltages.

It will be noted that the above conditions require a gradient of 100 kv/ft. (330 kv/m.) in the most dense part of the electric

FIG. 2.


Electric Field and Potentials in Space Caused by Charged Cloud
Table
Distance from Point Directly Beneath Cloud
g
Voltage Induced on a Line Twenty ft. High
0 Mile 100 Kv/ft. 2000 Kv.
¼ Mile 31.9 Kv/ft. 638 Kv.
½ Mile 12.4 Kv/ft. 248 Kv.
1 Mile 3.6 Kv/ft. 72 Kv.
2 Mile 0.9 Kv/ft. 18 Kv.
Cloud 1000 feet Above Earth and at a Potential of 100,000,000 Volts
Cloud
g=100 Kv. per ft.
g=31.9 Kv. per ft.
g=12.4 Kv. per ft.
g=3.6 Kv. per ft.
0 Mile
¼ Mile
½ Mile
1 Mile

field where the flash occurs, and a gradient of less than half of this value a short distance from the flash. (Fig. 2.)

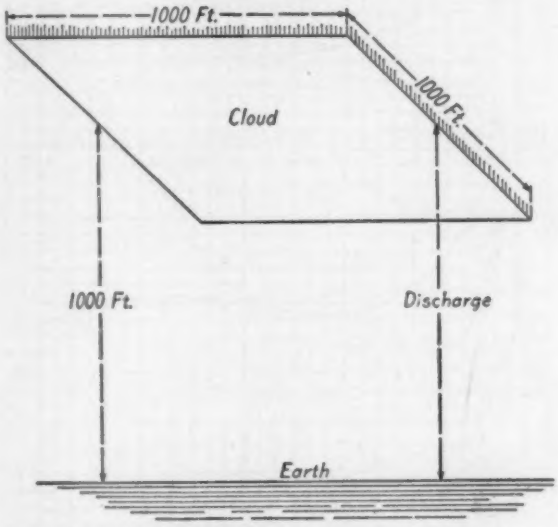
Norinder has recently measured voltage gradients during a lightning storm which confirm the values given above.[3] To quote from his article in the *Electrical World*—" field intensities of the order of 100 kv per metre are common during thunderstorms at about the height of a normal power transmission line. Pressures of 200 kv per metre have also been recorded. A closer study of the records shows that in the regions near the lightning path, field intensities of the order of 300 kv to 400 kv per metre may exist." De Blois observed corona brushes of considerable dimensions. This also is an indication of gradients of the above order.

[3] H. Norinder, " Electric Thunderstorm Field Researches," *Elec. World*, Feb. 2, 1924.

CHARACTER OF A LIGHTNING DISCHARGE.

Experimental data seem to show that for the most part, lightning discharges are impulses of very steep wave front, although some discharges are of impulses of slanting wave front and some are oscillatory. Oscillographic measurements made by De Blois on discharges from antennæ showed that 60 per cent. of the discharges were of steep wave front.[4] Similar studies recently made by Norinder indicate impulses of slanting wave front.

FIG. 3.



"Cloud" assumed for calculation of waves shown in Fig. 4.

However, it is not possible to determine from oscillographic records just how steep such waves are, because of the relative slowness of the apparatus in responding. Other observations, however, indicate the order of the steepness of the wave front. When an impulse voltage is measured by a needle gap and a sphere gap, the sphere indicates approximately the true value of the voltage while the needle indicates a much lower value.[5] The ratio of these voltages indicates the steepness of the wave front. From

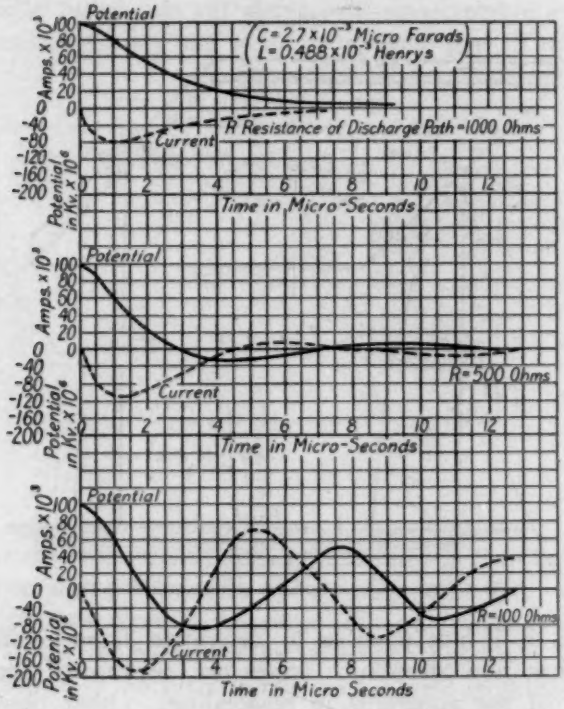
[4] L. A. De Blois: "Some Investigations on Lightning Protection of Buildings," *A.I.E.E.*, Vol. 33, p. 519, 1914.

[5] F. W. Peek, Jr.: "The Effect of Transient Voltages on Dielectrics," *A.I.E.E.*, Vol. xxxiv, p. 1857. "Lightning," *G. E. Rev.*, July, 1916.

observations on transmission lines, the author has found impulses corresponding to single half cycles of 200 kv sine waves and also of impulses of very much greater steepness with an impulse ratio of two.

Certain assumptions as to size of cloud and length of discharge will be made and the wave calculated to see if the above obser-

FIG. 4a.

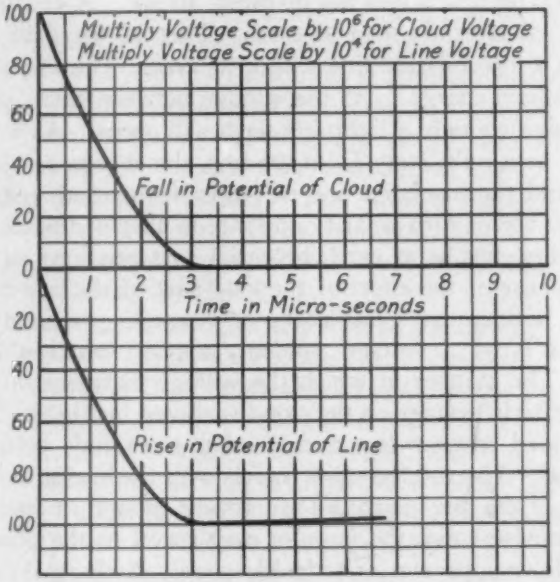


vations seem reasonable. Although such a check is quite rough, it should give good indications as to what type of wave can occur.

Assume that a cloud 1000 feet (305 metres) square and 1000 feet (305 metres) high, uniformly charged, discharges to earth. (Fig. 2.) The capacity of such a cloud is approximately 27×10^{-10} farads and the inductance of the path is .000488 henry. If the resistance of the discharge is 1000 ohms, the discharge is an impulse and non-oscillatory. The time is conveniently

measured in microseconds. Fig. 4 is quite in agreement with observations. Fig. 4 also shows that the wave is practically an impulse with a resistance of 500 ohms for the discharge path, and that it is a damped oscillation for 100 ohms resistance. The ratio of increase in voltage on the line with decrease in voltage on the cloud is of interest. It is certain that the cloud condenser

FIG. 4*b*.



Transients for cloud discharge to earth.

is not as simple as the example taken and the probabilities are that there are local flashes in the cloud before the final flash occurs.

At 100,000,000 volts, the maximum current would be 78,000 amperes. The stored energy would be 13,500 kw/sec., or 3.8 kw/hour.

On the line referred to above, 1 per cent. of the lightning voltage and one-ten-thousandth of the energy (1350 watt-seconds) would appear by induction. The author's lightning generator supplies 2000 kv above ground and 2000 watt-seconds at approximately the same rate as the lightning cloud.

LIGHTNING ON POWER TRANSMISSION LINES.

A power transmission line offers an ideal means of investigating the characteristics of lightning, since these characteristics are reproduced on the line at reduced scale. A study of disturbances on lines is also important from the standpoint of the line itself. This subject has been discussed in a recent paper.[6] Part of this discussion will be given here.

Most lightning disturbances on transmission lines occur by electrostatic induction and not by direct stroke. A charged cloud causes an electrostatic field to earth. Part of the field will terminate on a transmission line within its area. The line is said to have a "bound charge." If the voltage between earth and cloud becomes high enough, a lightning flash will occur. Although this flash may be a mile away from the line, the charge on the line is released and the insulated line increases from earth potential to some value above with polarity opposite to that of the cloud. An insulated line can be at earth potential just previous to the discharge because of the effect of the long part of the line not under the cloud, leakage over insulators or through grounded neutral. The effect is of a voltage suddenly applied between line and ground. The manner in which the voltage increases on the line with decrease in voltage on the cloud is shown in Fig. 4. The field that extended between line and cloud now extends between line and ground. The voltage wave travels over the line at the velocity of light. If the line insulators are strong enough or have a high enough impulse ratio, the impulse may travel to the powerhouse to break down apparatus or to be harmlessly discharged to ground over the arrester, if it has low resistance and low impulse ratio. As this lightning wave travels over the line it becomes gradually dissipated by losses. The voltage that the line assumes at the instant of discharge is that of the equipotential surface at the point in which the line is located. This is a certain percentage of the voltage of the lightning bolt. In studies in Colorado, as already stated, the author has actually measured induced lightning voltages on transmission lines as high as 500,000 volts. Insulator flash-overs have occurred that indicate induced voltages as high as 1,500,000 volts, although the greater percentage of voltages induced on transmission lines are very much lower than this.

[6] F. W. Peek, Jr.: "Lightning on Transmission Lines," *Jour. A.I.E.E.*, August, 1924.

These figures, as already shown, afford a means of estimating the voltage of a lightning flash.

Variation of the Lightning Voltage with the Height of Line.—Fig. 2 shows the lines of force from a charged cloud. Transmission lines of equal height are shown, one right under the cloud and others some distance away. It will be noted that for the line under the cloud, the gradient is 100 kv/ft. (330 kv/m.), but it is much less a short distance away. The gradient is high immediately under the cloud. It will also be noticed that the voltage for any line will vary approximately as the height of the line, because the field over relatively short distances is approximately uniform. No attempt is made, because of the scale, to show the flux terminating upon the line. When a discharge takes place from cloud to ground, the line takes the potential of the equipotential surface in which it is located. The induced lightning voltage on a transmission line thus varies approximately as the height of the line. It is also approximately equal to the height of the line times the voltage gradient. Note that the voltage decreases very rapidly with increasing distance from the cloud.

The Maximum Lightning Voltages on Transmission Lines.—It was shown above that the maximum possible voltage gradient during a lightning storm was about 100 kv/ft. (330 kv/m.). This gradient would determine the voltage induced on the line if it were directly under a cloud charged to a voltage sufficient to discharge it to earth or to the line. Generally this condition will exist only in cases of direct stroke and gradients for very severe storms will be of the order of 50 kv/ft. (165 kv/m.), while for the majority of storms gradients will be much lower than this. Low gradients will also exist for cloud-to-cloud discharges, which are generally in the majority.

The variation in voltage with height of tower is given in Table I. The voltages were found by multiplying the height of tower by the gradient caused by the cloud. In the second column, the maximum voltage was found by using a gradient of 100 kv/ft. As previously stated, this is the gradient necessary to cause the lightning flash, and can only apply to the line when it is directly under the storm centre. The voltages in the third column were found by using a gradient of 50 kv/ft. Such a gradient occurs when the line is about 1000 feet from the projection of the storm centre. It is a severe condition and does not

usually occur. In column 4, a gradient of 100 kv/ft. was used, while a gradient of 50 kv/ft. was used in columns 5 and 6. All these conditions are severe and unusual. The voltages are for the instant that the flash occurs, and before possible insulator arc-overs can take place.

These figures are, of course, not exact, but probably give the order of the voltage that might occur on a badly exposed line in a very severe storm directly over the line. Data obtained in Colorado for twenty-four miles of a badly exposed line on a high

TABLE I.

*Lightning Voltages on Transmission Lines.**

(Kilovolts Maximum.)

Height of Tower. Ft.	No Ground Wire.		Ground Wire.			Lightning Flash-over Voltage of Line Insulator.		
	Theoretical Highest.	Probably Usual Highest.	Direct Stroke to Ground Wire (One Wire).	Usual Highest (One Ground Wire).	Usual Highest (Three Ground Wires).	220 kv line	154 kv line	110 kv line
75	7500	3750	3750	1875	900	——	——	——
50	5000	2500	2500	1250	625	1800	——	——
40	4000	2000	2000	1000	500	1800	1400	900
30	3000	1500	1500	750	375	1800	1400	900
20	2000	1000	1000	500	250	——	——	——

For a grounded line the voltage above ground just before the discharge would be zero. For an isolated system the line would not assume the above voltage before the discharge as there would be leakage over insulators and arresters and much static. There would also be a reduction of the static voltage by the section of the line not under the cloud.

* The voltage values given assume no insulator flash-over. Actually, the highest value at the tower is limited by the insulator flash-over voltage.

mountain ridge, showed only one or two direct strokes in a season of fifty severe storms. Of the many lightning impulses induced on the line, very few exceeded 50 kv during a storm.

When the conductors of a transmission line are arranged in a horizontal plane, there should be no lightning voltage between them since they are all the same distance above ground. However, this is not the usual condition. For example, with a 220-kv line with conductors in a vertical plane, the voltage between the adjacent conductors would depend upon their relative distances above ground. This voltage might be of the order one-third of the voltage to ground.

Referring to Table I, note that the ground wire practically cuts the voltage values in half. The ground wire will be very

completely considered in a later section. The lightning spark-over voltages for insulators and bushings are given in the last column.[7] It will be noted that a 220-kv line is generally immune from lightning voltages high enough to cause insulator flash-overs.

Travel of Lightning on Transmission Lines.—An investigation was made of the travel of lightning on transmission lines. This investigation, which has already been fully treated in the

FIG. 5.

Lightning discharge from transmission line photographed on revolving film.

JOURNAL, shows that the voltage decreases and the wave becomes less steep as it travels along the line.[8] When an open end is reached, the wave increases in voltage and steepness of wave front. When an inductance is struck, the voltage increases in value; part of the wave passes through the inductance while part is reflected. The part of the wave that passes through

[7] F. W. Peek, Jr.: "The Effect of Transient Voltages," *A.I.E.E.*, Vol. xxxiv, p. 1857. "The Insulation of High Voltage Transmission Lines," *G. E. Rev.*, Feb., 1922. "High Voltage Power Transmission," *A.S.C.E.*, Vol. lxxxvi, p. 725.

[8] F. W. Peek, Jr.: "Dielectric Phenomena," JOUR. FRANK. INST., Jan., 1924. "The Effect of Transient Voltages," Vol. iii, *A.I.E.E.*, June, 1923.

the inductance may build up to very high values. This is not the case if the inductance is shunted by a resistance. Corona loss helps greatly to lower the voltage of a travelling wave.

Secondary Discharges, Switching and Arcing Grounds.—When an arc occurs on a transmission line, oscillations result that

TABLE II.

Duration and Frequency of a Lightning Discharge from a Transmission Line.

("High Line" Twenty-four Miles Long.)

Film.	Half Oscillations.	Duration Seconds.	Frequency.	Gap Setting Voltage to Ground kv.	Fuse Blown.
1a	12	.0031	1930	20	
1b	6	.0018	1660	20	
2a	8.5	.0022	1930	20	
2b	8.5	.0025	1700	20	Multiple Stroke
	6.5	.0017	1880		
2c	4.5	.0013	1730	20	
2d	5	.0016	1560	20	Multiple Stroke
	4.5	.0014	1600		
2e	5	.0017	1470	20	
2f	6	.0017	1800	20	
2g	6.5	.0019	1700	20	
3a	10	.0031	1600	20	1 strand .0036
3b	9	.0029	1550	20	Multiple Stroke
	6	.0026	1500		
4a	1	.0002	2000	35	1 strand .0036
4b	1	.0002	2000	35	
4c	1	.0002	2000	35	
4d	1	.0002	2000	35	
4e	1	.0002	2000	35	
4f	1	.0002	2000	35	
5a	8	.0020	2000	20	
5b	7	.0019	1840	20	
5c	11	.0026	2100	20	1 strand .005 broken
5d	7.5	.0020	1850	20	

have the effects of lightning. In 1907 and 1908 the author conducted some tests in the mountains of Colorado.[9] A twenty-four-mile idle line was available. The lightning was permitted to discharge to ground through a large gap in series with a small auxiliary gap in a dark box. A rapidly revolving photographic film on a steel disc recorded the discharge. Many of these discharges were photographed. In all cases, following the first

[9] E. E. F. Creighton: "Measurements of Lightning," *A.I.E.E.*, Vol. xxvii, p. 669.

impulse, a very highly damped oscillation took place at the natural period of the line or about 1900 cycles. Fig. 5 gives an example of one of the many records taken. A few of the records are given in Table II.

The duration values given in the tables are a measure of the duration of the secondary oscillations and not of the lightning stroke. The "duration" measurements by De Blois are of the same order of .05 second. The above instrument did not record the first impulse, but the oscillations following the arc-over. Other observations indicate that in general there is a very steep impulse followed, when breakdown occurs, by a highly damped oscillatory discharge of the line at its natural period. This oscillation is of comparatively low frequency. When there is an arcing ground, especially on a system with an isolated neutral, oscillations occur. These oscillations appear to be highly damped and have the effect of lightning impulses.[10] High voltage undamped oscillations cannot occur because of corona losses which increase as the square of the voltage above the starting voltage and almost directly with the frequency. This also applies to damped oscillations of high train frequency.

Damped oscillations rarely reach double the operating average on a transmission line, although higher values can be reached locally, due to inductance or in transformers.[11]

Insulator arc-over voltages are always higher for the types of transient voltages that occur on transmission lines than they are at sixty cycles.[12] "Dirt" and moisture on dirty insulators may lower the sparking voltage so that arc-overs can occur at normal operating voltage. Much of such trouble has been ascribed to "high frequency."

THE GROUND WIRE.

When a grounded conductor or ground wire is placed near the conductors of a transmission line, it has a marked effect on the voltages that appear on the line due to lightning. A laboratory study of the ground wire has been made on a model in which the

[10] G. Faccioli: "Electric Line Oscillations," *A.I.E.E.*, Vol. xxx. W. W. Lewis: "Switching Operations," *G. E. Rev.*, Oct., 1913.

[11] J. Murray Weed: "Prevention of Transients in Windings," *A.I.E.E.*, Sept., 1915, Feb., 1922. L. F. Blume and A. Boyajian: "Abnormal Voltage in Transformers," *A.I.E.E.*, Feb., 1919.

[12] F. W. Peek, Jr.: "Dielectric Phenomenon in High Voltage Engineering," McGraw-Hill.

size of the conductor, conductor spacing, height of line, etc., were all reduced to scale. Since the first report of this investigation, the tests have been extended to include all practical conditions.[13]

These tests show that it is possible with a favorably installed ground wire to reduce induced lightning voltages to from one-half to one-third of the value of those induced on unprotected lines. The ground wire also offers protection against direct strokes. When it is possible to obtain the protection mentioned above, the higher voltage lines should be practically free from lightning trouble.

Theoretical studies of the ground wire have been made.[14] Methods of making the calculations are also found in textbooks.[15] In general, the experimental work checks the theoretical work. There are conflicting reports from operating companies as to the protective value of the ground wire. Probably approximately half of the reports are in favor of and half against the ground wire. The reason for this seems to be apparent from this investigation. The ground wire gives the high value of protection mentioned if the ground is good and the reactance of the ground connection is low. In a dry country, with poor grounds, its protective value against induced strokes would be low. On the other hand, in a damp country its protective value should be high. Its protective value would be low if grounds were made infrequently, since there would then be a considerable length of wire or inductance between the ground wire and the ground connection.

Complete data are given in the tables for the various factors affecting the ground wire. These will be discussed in detail.

Induced Strokes.—The arrangement for studying induced strokes on transmission lines is shown in Fig. 6. The plate represents the position of the cloud which causes a steady electrostatic field to ground in the vicinity of the transmission line. The complete cloud includes the condenser of the lightning generator. This field is in reality a 60-cycle a.c. field, but at the instant of discharge of the clouds to earth is in effect a steady field. Due to

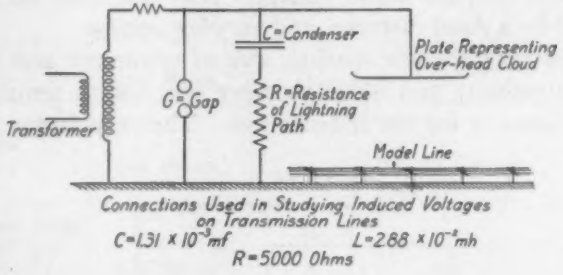
[13] F. W. Peek, Jr.: "High Voltage Phenomena," JOUR. FRANK. INST., Jan., 1924.

[14] W. Peterson: "The Protective Value of the Ground Wire," *E.T.Z.*, Jan., 1914. E. E. F. Creighton, "Theory of Ground Wires," *A.I.E.E.*, 1910, p. 448.

[15] E. J. Berg: "Electrical Engineering—Advanced Course," McGraw-Hill.

this field all points in the intervening space have a definite potential. The space in the vicinity of the line has a certain percentage of the lightning potential above earth. When the condensers discharge, the charge on the transmission line is released and the line assumes the potential of the equipotential surface in which it is

FIG. 6.



located. (See Fig. 4.) The voltage of the cloud P and of the transmission line can be accurately measured; the voltage of the cloud to ground by spheres and the voltage of the lines to ground by small needle gaps mounted to give minimum capacity. The

TABLE III.

Actual Dimensions of Model Lines.

Dimension of Cloud.—5′ x 7½′ (152 cm. x 229 cm.) Horizontal plate with rounded edges.

Height of Cloud above Ground.—43½″ (112 cm.) Unless otherwise stated.

Height of Line.	Size of Conductor. Diameter.	Spacing.
12″ (30.5 cm.)	.040″ (.102 cm.)	3″ (7.6 cm.)
6″ (15.2 cm.)	.020″ (.051 cm.)	1½″ (3.8 cm.)
3″ (7.9 cm.)	.010″ (.025 cm.)	¾″ (1.9 cm.)
1¼″ (3.9 cm.)	.005″ (.012 cm.)	3.8″ (.9 cm.)

Ground Wire.—Same size as line wire and, unless otherwise stated, conductor spacing from nearest conductor.

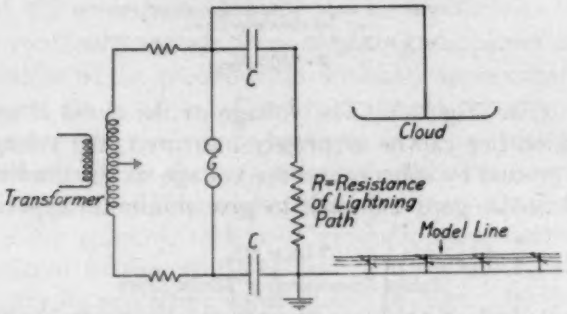
Lightning Generator Constants.—
Resistance, 5000 ohms. Cap. = 1.3 x 10^{-3} mf. L = 2.88 x 10^{-3} mh.

ratio of the conductor diameter to spacing, etc., was selected to correspond to practical conditions. Tests were made with the transmission line grounded through high resistance to represent the grounded neutral system and also without grounds. The results were practically the same.

The height of the cloud is not important in determining the induced voltage or the protective value of the ground wire. It can be shown mathematically that since the field is practically uniform between the line and earth, the induced voltages depend only on the voltage gradient in this part of the field. A given voltage gradient may be caused by a high cloud and high cloud voltage or a low cloud with low cloud voltage. Any condition may thus be simulated by a fixed distance, and varying voltage.

By reducing the line spacing, size of conductor and height to scale, the capacity and inductance *per unit length* remain practically the same as for the full-size line. The only factor that does

FIG. 7.



Connections used in studying voltages on transmission lines.

not correspond is the resistance. It is relatively higher. However, it is not believed that this materially affects the results. It might also be well to point out that with equal voltage gradients the induced voltage will be much lower in the model than on an actual line. This follows because the voltage is approximately equal to the height of line times the gradient.

The length of the artificial cloud has no particular meaning except that it is long enough to produce a practically uniform field.

It will be noted from Table IV that the protective value of the ground wire is quite high and the same for all cloud heights as theory would indicate. With one ground wire the voltage is practically cut in half. This also conforms with theory. The last column in Table IV is called the protective ratio. A ratio of .43 means that the induced voltage on the line with a ground wire is .43 of that on a line without a ground wire.

The data in Table IV show that the protective ratio of the

TABLE IV.

Induced Voltages on Transmission Lines with and without Ground Wire. Protective Value of Ground Wire Line by Scale 30′ (9.1 m.) Conductors Spaced 7.5′ (2.3 m.) Size, 1.2″ (3 cm.) Lightning Voltages 372 kv.

Arrangement.	Scale Distance to Cloud above Line.	Induced Voltage.	Per Cent. of Lightning Voltage Induced on Line.	Protective Ratio of Ground Wire. Voltage with Ground Wire. / Voltage without Ground Wire.
No ground wire 000	216′ (66 m.)	33	9	
Ground wire above centre line 0 000	216′ (66 m.)	14.7	4	.43
Three ground wires above line 000 000	216′ (66 m.)	8.7	2.3	.26
No ground wire 000	864′ (264 m.)	8.0	2.1	—
No ground wire 000	Irregular field	6.3	1.70	
Ground wire 0 000	Irregular field	3.3	.9	.52

TABLE V.

Effect of Connection of Lightning Generator on Induced Voltage and Protective Value of Ground Wire.

Connection of Generator.	Arrangement of Line.	Induced Voltage.	Protective Ratio.
Fig. 7	No ground wire	29	.48
	Ground wire	14	
Fig. 6	No ground wire	23.4	.47
R = 5000 ohms	Ground wire	11.1	
Fig. 6	No ground wire	23	.51
R = 0 ohms	Ground wire	11.8	
Fig. 8	No ground wire	17.9	.45
	Ground wire	8.2	

TABLE VI.

Effect of Ground Wire Arrangement.

Arrangement.	Height of Line.		Voltage Induced on Line.		Protective Ratio.
	Actual of Model.	To Scale.	Actual of Model.	To Scale.	
No ground wire dist; "S" above centre wire. O–S–O–S–O	6″(15.3 cm.)	30′(9.2 m.)	29.8	1788	——
One ground wire o ooo	6″(15.3 cm.)	30′(9.2 m.)	14.3	858	0.48
Two ground wires o o ooo	6″(15.3 cm.)	30′(9.2 m.)	10.2	612	0.34
One line wire Four ground wires · ·o·	6″(15.3 cm.) 6″(15.3 cm.)	30′(9.2 m.) 30′(9.2 m.)	1.7	102	0.06
One line wire Three ground wires · .o.	6″(15.3 cm.)	30′(9.2 m.)	4.7	282	0.16
One ground wire S/2 above centre wire	6″(15.3 cm.)	30′(9.2 m.)	12.9	774	0.43
One ground wire 2S above centre wire	6″(15.3 cm.)	30′(9.2 m.)	17.0	1020	0.57
Four ground wires o s os o s o s oos o s o	6″(15.3 cm.)	30′(9.2 m.)	2.7 2.7 2.7		0.09 0.09 0.09
Three ground wires · A B C ·o o o·	6″(15.3 cm.)	30′(9.2 m.)	A7.2 B4.2 C7.2		0.24 0.14 0.24
Three ground wires ·o o o· ·	6″(15.3 cm.)	30′(9.2 m.)	7.2 5.2 7.2		0.24 0.18 0.24
One ground wire o o o ·	6″(15.3 cm.)	30′(9.2 m.)	16		0.54

S = 1½″

ground wire is not materially changed over a wide range of waves or varying connections on the lightning generator.

Various Arrangements of Ground Wires.—The data in Table VI give the protective value of the ground wire over a

TABLE VII.

Comparison of Induced Lightning Voltages on Grounded and Non-grounded Neutral Systems.

Line Arrangement.	Height of Line.		Voltage Induced on Line.		Protective Ratio of Ground Wire.
	Actual of Model.	To Scale.	Actual of Model.	To Scale.	
No ground wire.....	6″(15.3 cm.)	30′(9.2 m.)	29.8	1788	—
Ground wire above centre line.....	6″(15.3 cm.)	30′(9.2 m.)	14.4	864	0.43
No ground wire..... Power lines grounded through resistance ("neutral grounded")	6″(15.3 cm.)	30′(9.2 m.)	33.1	1986	—
Ground wire..... "Neutral grounded"..	6″(15.3 cm.)	30′(9.2 m.)	14.7	882	0.45

TABLE VIII.

Comparison of Induced Voltages for Constant Cloud and Different Heights of Line.

Line Arrangement.	Height of Line.		Voltage Induced on Line kv.		Protective Ratio of Ground Wire.	Average Gradient Near Line.	
	Actual of Model.	To Scale.	Actual of Model.	To Scale.		kv/ft.	kv/m.
No ground wire...	6″(15.3 cm.)	30′(9.2 m.)	23.3	1398	—	46.6	152
Ground wire above centre of line....	6″(15.3 cm.)	30′(9.2 m.)	11.0	660	0.47	—	—
No ground wire...	12″(30.5 cm.)	60′(18.3 m.)	48.7	2922	—	48.7	159
Ground wire above centre line.....	12″(30.5 cm.)	60′(18.3 m.)	24.0	1440	0.47	—	—

wide range of possible practical arrangements. The efficiency of the ground wire decreases as its distance from the conductors increases. The protective values given are for spacing between conductors and ground wire equal to the spacing between conductors.

When properly installed, one ground wire reduces the lightning voltages to approximately one-half; two to one-third, and three to one-fourth.

TABLE IX.

Effect of Cloud Voltage.

Arrangement.	Height of Line.		Voltage Induced on Line.		Protective Ratio of Ground Wire.	Lgt. Voltage p.c.
	Actual of Model.	To Scale.	Actual of Model.	To Scale.		
No ground wire....	6"(15.3 cm.)	30'(9.2 m.)	33.0	1980	——	100
Ground wire.....	6"(15.3 cm.)	30'(9.2 m.)	14.7	882	0.45	100
No ground wire....	6"(15.3 cm.)	30'(9.2 m.)	16.2	972	——	50
Ground wire.....	6"(15.3 cm.)	30'(9.2 m.)	7.3	438	0.45	50
No ground wire....	6"(15.3 cm.)	30'(9.2 m.)	8.2	492	——	25
Ground wire.....	6"(15.3 cm.)	30'(9.2 m.)	——	——	——	25
No ground wire Irregular field.....	6"(15.3 cm.)	30'(9.2 m.)	6.3	378	——	——
Ground wire Irregular field.....	6"(15.3 cm.)	30'(9.2 m.)	3.3	198	0.52	——

TABLE X.

Comparison of Induced Lightning Voltages for Cloud-to-Ground Discharge and Impulsive Discharge from Cloud to Cloud.

Line Arrangement.	Height of Line.		Voltage Induced on Line.		Protective Ratio of Ground Wire.	Average Gradient before Discharge.	
	Actual of Model.	To Scale.	Actual of Model.	To Scale.		kv/ft.	kv/m.
No ground wire.	6"(15.3 cm.)	30'(9.2 m.)	23.0	1380	——	46	150
Ground wire above centre line....	6"(15.3 cm.)	30'(9.2 m.)	11.1	666	0.48	——	——
No ground wire*	6"(15.3 cm.)	30'(9.2 m.)	17.9	1074	——	0	0
Ground wire above centre line*...	6"(15.3 cm.)	30'(9.2 m.)	8.2	492	0.46	——	——

*Impulsive discharge to "dead" cloud above line and to ground. See Fig. 8.

Comparative Value of the Ground Wire on Grounded and Non-grounded Neutral Systems.—The ground wire is equally effective on grounded and non-grounded neutral systems. It is interesting that the induced voltage is generally slightly higher

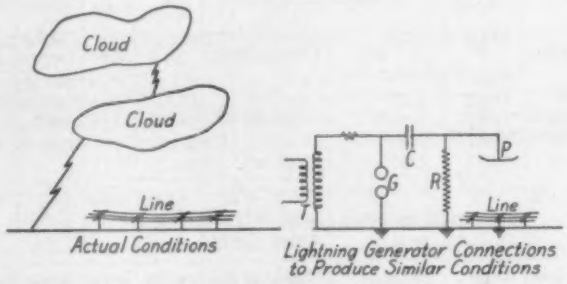
on grounded neutral systems. This is shown by the data in Table VII.

Induced Voltages and Effectiveness of Ground Wires for Lines of Different Heights.—By doubling the height of the line, the lightning voltage *induced on the line is approximately doubled.* The protective ratio of the ground wire is not changed. This is shown in Table VIII.

By referring to Table IX it is seen that the protective ratio is not affected by the lightning voltage.

Effect of Type of Discharge on the Value of the Ground Wire.—With the exception of Table V, the data so far dis-

FIG. 8.



Impulsive discharge. Discharge takes place, from upper to lower cloud, then from lower cloud to ground.

cussed have been for voltages induced by cloud-to-cloud or cloud-to-ground discharge with a steady field between cloud and line at the instant previous to discharge. A different type of discharge is possible. There might be a cloud at near ground potential directly above the line, while above this cloud there might be another at a very high potential. (Fig. 8.) A discharge between these clouds could, in turn, cause an impulsive discharge between cloud and ground. This would induce a voltage on the line. A model of this arrangement was made with the results as given in Table X. The protective value of the ground wire is the same as for the other types of discharge.

The Ground Wire Where the Soil Is Conducting and Non-conducting.—The ground wire is not effective where the soil is dry and good grounds are not possible.

Tests were made to determine the relative value of the ground

wire when used in dry and damp soil. A long box with a metal bottom was filled with six inches of sand. The six-inch line was placed upon the top of the sand. Referring to Table XI, the first two tests were made with a metal plate on the surface of the sand as a conducting ground. The next three tests were made with the sand ground and with the " water level " below the sur-

TABLE XI.

Comparison of Induced Lightning Voltages with Conducting and Non-conducting Soils.

Line Arrangement.	Height.		Nature of Soil.	Voltage Induced on Line.		Protective Ratio of Ground Wire.	Average Gradient near Line.	
	Actual of Model.	To Scale.		Actual of Model.	To Scale.		kv/ft.	kv/m.
No ground wire	6" (15.3 cm.)	30' (9.2 m.)	Conducting	33.0	1980	—	66	216
Ground wire above centre line	6" (15.3 cm.)	30' (9.2 m.)	Conducting	14.7	882	0.45	—	—
No ground wire	6" (15.3 cm.)	30' (9.2 m.)	Top dry sand 6" to water level	37.0	2220	—	74	—
Ground wire above centre line Grounded at water level	6" (15.3 cm.)	30' (9.2 m.)	Top dry sand 6" to water level	19.8	1188	0.53	—	—
Ground wire above centre of line. Poor ground made by driving nail in sand	6" (15.3 cm.)	30' (9.2 m.)	Top dry sand 6" to water level	34.6	2078	0.98	—	—

face at a distance equal to the height of the line. By comparing tests 1 and 3, it is seen *that under equal conditions the induced voltage is higher when the soil is dry.* This follows because the flux extends from cloud to water level. The effect is that of increasing the height of line. Test 4 shows that the ground wire is effective providing connections are made to water level. Test 5 shows that it is not effective with a poor ground connection.

The Effect of Inductance or Resistance in Series with the Ground Wire.—The ground wire reduces the voltage by reducing

the initial charge or the flux terminating on the line and by increasing the capacity to ground. This capacity has in series with it, however, the inductance and resistance of the ground connections. If a lightning discharge took place without time, the initial instantaneous voltage would be the same with or without a ground wire. The tests so far have shown that there is suffi-

TABLE XII.

Effect of Resistance in "Ground."

Arrangement.	Height of Line.		Voltage Induced on Line.		Resistance or Reactance. Ohms or Millihenrys.	Protective Ratio.
	Actual of Model.	To Scale.	Actual of Model.	To Scale.		
No ground wire....	6″(15.3 cm.)	30′(9.2 m.)	33.1	1990		
Ground wire above centre. Resistance in series with ground connection.....	6″(15.3 cm.)	30′(9.2 m.)	15.7	942	0	0.47
	6″(15.3 cm.)	30′(9.2 m.)	18.4	1100	855	0.55
	6″(15.3 cm.)	30′(9.2 m.)	20.0	1200	1430	0.60
	6″(15.3 cm.)	30′(9.2 m.)	17.5	1050	1700	0.53
	6″(15.3 cm.)	30′(9.2 m.)	24.9	1500	4400	0.75
Effect of Reactance in Ground Wire.						
No ground wire....	6″(15.3 cm.)	30′(9.2 m.)	33.1	1990		
Ground wire above centre. Inductance in series with ground connection.....	6″(15.3 cm.)	30′(9.2 m.)	13.8	828	0.08	0.42
	6″(15.3 cm.)	30′(9.2 m.)	16.6	995	0.11	0.50
	6″(15.3 cm.)	30′(9.2 m.)	18.4	1100	0.13	0.55
	6″(15.3 cm.)	30′(9.2 m.)	14.8	888	0.46	0.45
	6″(15.3 cm.)	30′(9.2 m.)	25.0	1500	0.98	0.75
Long wire line to ground.....	6″(15.3 cm.)	30′(9.2 m.)	13.8	828	10′	0.42
	6″(15.3 cm.)	30′(9.2 m.)	13.8	828	50′	0.42
	6″(15.3 cm.)	30′(9.2 m.)	17.4	1045	100′	0.52

cient delay so that the inductance does not produce an appreciable effect with short wire connections. Tests were also made with long ground connections and with series reactance. They show that the protective value of the ground wire could be greatly reduced in practice by resistance in the ground connection or by considerable distance between grounds causing high inductance. Thus, in a long span the induced voltage would be highest in the centre of the span and minimum at the tower.

The actual values of resistance and inductance used, as well as length of ground connections, are given in Table XII. These

values do not apply directly to a practical line since the voltage and the energy on the actual line would be much higher. It is difficult to correct these to equivalent conditions for an actual line. It is safe to say that the values must be much smaller than those indicated to make an effective ground wire. They emphasize the importance of short low-resistance-low-reactance ground connec-

TABLE XIII.

Arrangement.	Number of Strokes Applied.	Number Striking Line.	Number Striking Ground Wire.	Number Striking Ground.
Connections—Fig. 6				
No ground wire. Conducting soil. No needle on cloud	105	14	——	82
Ground wire. Conducting soil. No needle on cloud	102	0	35	67
No ground wire. Six-inch sand. No needle on cloud	102	59	0	
Ground wire. Six-inch sand. No needle on cloud	102	1	76	
No ground arcs. Three-inch sand. Needle on cloud	104	91	——	
Ground wire. Three-inch sand. Needle on cloud	102	0	96	
Connections—Fig. 8				
No ground wire. Needle on cloud. Conducting soils	100	100	——	
Ground wire. Needle on cloud. Conducting soils	100	2	98	

tions. Fortunately, the modern steel tower affords a low inductance path to ground. Both resistance and inductance should be made as low as possible.

Electromagnetic Induction.—The voltages measured on the line wires protected by ground wires are made up of the electromagnetic induction and electrostatic induction due to the induced current in the ground wire. The electromagnetic induction was found to be negligible. High impulse currents from the lightning generator were sent through the ground wire without causing high voltage in the lines.

Direct Strokes.—The ground wire is of value in case of direct strokes. In the experimental work on direct strokes the voltage was increased so that the discharge would take place almost directly over the ground wire. It will be seen by referring to Table XIII that the ground wire offers good protection from direct strokes. There seems to be greater chance for an unprotected line to be struck in a dry soil than in a wet soil. In these tests the connection used was that in Fig. 6.

Tests were also made with the impulsive discharge of Fig. 8. This type of discharge was early recognized by Lodge. It is more difficult to predict where it will strike than for the steady discharge. In these tests about 2 per cent. of the hits struck under the ground wire to the line. The data will be found in Table XIII. It appears that the ground wire will give almost complete protection against direct strokes on the line.

These tests indicate why direct strokes are so rare in practice. With everything deliberately arranged for the spark to take place to the line projecting above a "plain," it very frequently took place elsewhere. In practice the chances of a direct stroke would be very small, first, because the cloud arrangement would not be deliberate and, secondly, because the chances would be lessened by trees, hills, etc. The same would apply to high induced strokes because they necessitate a very high-voltage cloud near the line. Here, too, hills and valleys would be helpful. More will be said of the chance of being struck in the discussion of the lightning rod.

INSULATING A TRANSMISSION LINE TO WITHSTAND LIGHTNING.

The investigation has shown the maximum lightning voltages that can occur on transmission lines with and without a ground wire. It is of interest to compare these voltages with the lightning insulator arc-over voltages for modern transmission lines.

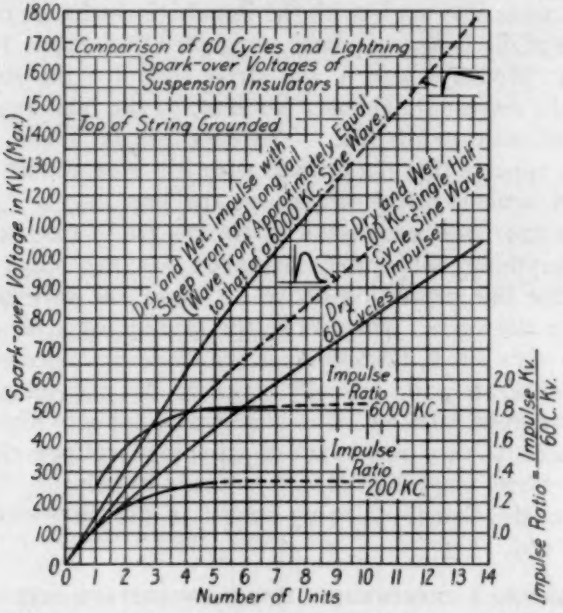
The lightning spark-over voltage for insulators and the lightning breakdown voltage for insulation is always higher than for steady voltages. In fact, this is true for all transient voltages that can occur on transmission lines. Rain lowers the arc-over voltage of insulators at sixty cycles, but does not reduce the lightning spark-over voltage.[16] The curves of insulator spark-over

[16] F. W. Peek, Jr.: "The Effect of Transient Voltages on Dielectrics," *A.I.E.E.*, "Dielectric Phenomena in High Voltage Engineering."

voltages for transient and operating conditions are given in Fig. 9.

The transient voltage curves cover the range of lightning, switching surges, and surges due to arcing grounds. The surges other than lightning are limited in value by the line voltage. Except as it is affected by the height of tower, lightning is independent of line voltage. It is the determining factor in insulation.

FIG. 9.

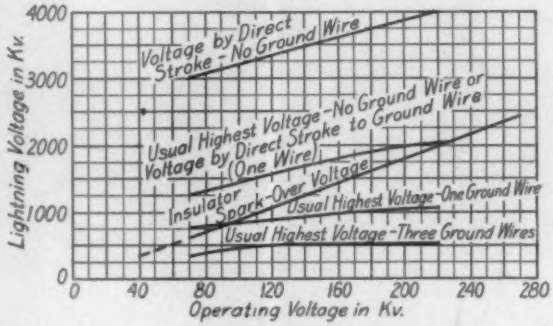

Comparison of 60 Cycles and Lightning Spark-over Voltages of Suspension Insulators
Top of String Grounded
Spark-over Voltage in Kv. (Max)
Dry and Wet Impulse with Steep Front and Long Tail (Wave Front Approximately Equal to that of a 6000 KC Sine Wave)
Dry and Wet 200 KC Single Half Cycle Sine Wave Impulse
Dry 60 Cycles
Impulse Ratio 6000 KC
Impulse Ratio 200 KC
Impulse Ratio = Impulse Kv. / 60 C. Kv.
Number of Units

The lightning flash-over voltage of insulators is plotted with operating voltage in Fig. 10. On this same figure are plotted curves of the probable highest lightning voltage for lines with and without ground wires. A direct stroke on a line without a ground wire causes voltages much higher than the insulator arc-over voltage. The second curve down represents the usual highest voltage on a line without a ground wire. It happens that this same curve corresponds to the voltage by a direct stroke on a line with one ground wire. This curve crosses the insulator spark-over voltage of 220 kv. This indicates that a 220-kv line without a ground wire is not likely to have insulator trouble from lightning except in case of direct stroke. It further indicates that a

220-kv line with a favorably installed ground wire is not likely to have trouble from lightning under any circumstances. The next curve gives the usual highest voltage for a line with one ground wire. Under usual conditions, very little trouble should be expected for lines insulated for over 100-kv operation. The lowest curve shows that three ground wires reduce the probability of lightning to still lower operating voltages. The probability of trouble with direct strokes would be reduced in proportion.

The values of voltages taken in the above curves are for the most severe storms directly over exposed lines. Such conditions

FIG. 10.



Insulator spark-over voltage compared with maximum lightning voltage for severe storms directly over the line.

might not occur during a year or several years. It is a well-established fact that during any storm there are likely to be induced many low-voltage impulses, a less number of moderate-voltage impulses and frequently none at high voltage.

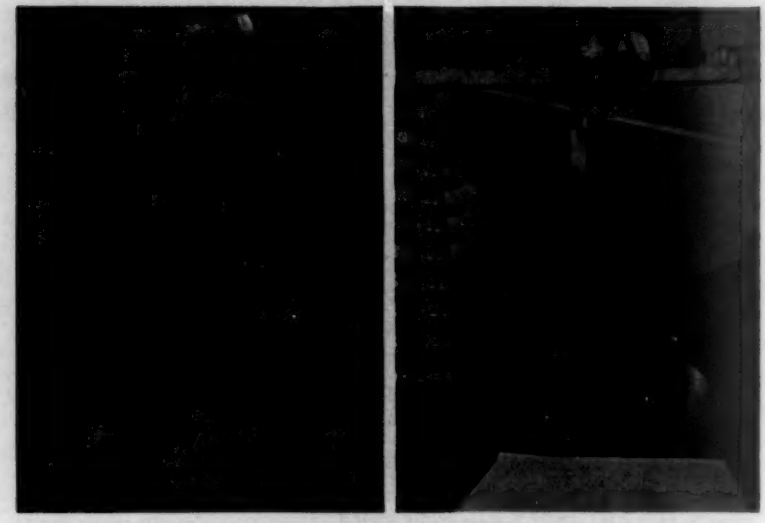
Lightning voltages are likely to cause high local stress in inductive apparatus such as transformers. In designing inductive apparatus to withstand lightning voltages, it is important to prevent concentration of stress. This can be done by means of shields. Like the ground wire, the action of the shield is preventative. Shields have been used on both line insulations and transformers.

LIGHTNING ARRESTERS.

Preventative methods of guarding against lightning on transmission lines, such as the ground wire, shields, and extra insulation, have already been discussed. The remaining method is the lightning arrester.

The object of the arrester is to permit transient or other excess voltages to discharge to earth and to suppress the dynamic arc that follows. Since transient currents are generally high, the arrester must have a low resistance. It must also have a low time

FIG. 11.



Lightning does not always hit the highest point.

lag, otherwise the transient voltage may rise to high values before the discharge occurs.

Fig. 10 shows that the need of an arrester becomes less as the operating voltage increases.

Corona and other losses also rapidly reduce lightning voltages.

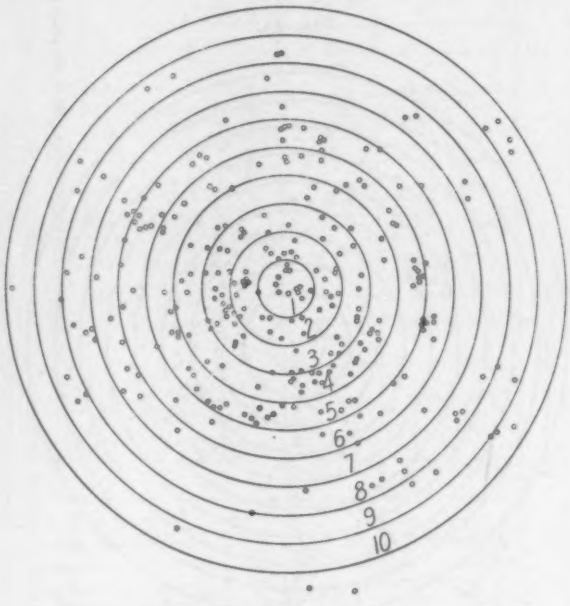
THE LIGHTNING ROD.

A study was made, using models built to scale, to determine the protective value of lightning rods. In making these tests, voltages varying from sixty cycles to oscillations and impulses were used. The "clouds" were also varied from a point to a large flat plane. It seems that all possible conditions were covered by this range and since the general behavior of the discharges was the same in all cases, it is believed the results apply to actual lightning discharges.

In making the tests the rod was placed in the centre of a large

piece of drawing paper on a flat plane. Unless otherwise stated, the plane was of metal. The cloud was placed above the rod. The tests show that lightning from a cloud overhead does not always strike the highest object. The discharges either took place to the rod or to the plane. When the discharge hit the paper a small hole was made. A record was thus obtained of the distri-

FIG. 12.



Target made by lightning. No needle.

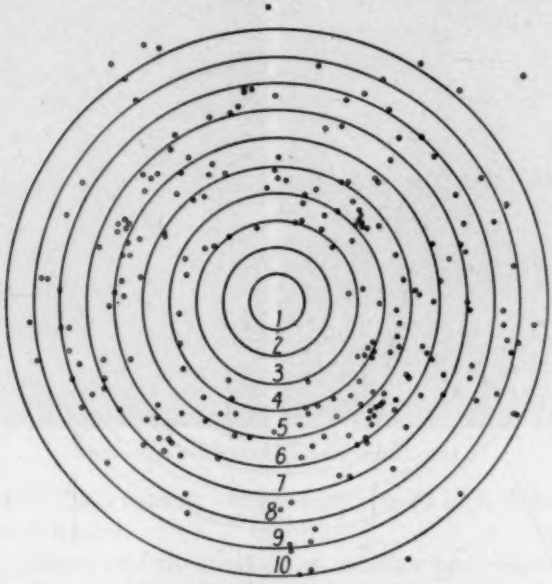
bution of the discharges. When the cloud was a plane, a small point was placed at its centre to represent the storm centre. The apparatus is shown in Fig. 11, while sample charts are shown in Figs. 12 and 13.

Area Protected by a Rod.—The general character of the division on hits between a rod and the surrounding ground is shown in Fig. 14. In this specific example, taken for illustration, the rod is located on a conducting plane and is 1.85 per cent. of the cloud height. In (*a*) Fig. 14, the storm centre is located directly above the rod. Under this condition 84 per cent. of the strokes hit the rod, while 16 per cent. hit the ground approximately as

shown in the shaded portion. There are no ground hits in an area between the rod and four rod lengths away. This protected area is well illustrated in Fig. 13, and seems to hold for all conditions as shown in Fig. 15.

The division of hits as the storm centre moves away from the rod is illustrated in (*b*) and (*c*) Fig. 14. Eventually, a distance is reached when the rod is no longer struck. This occurs for this

FIG. 13.



Target made by lightning. ½" needle.

particular rod when the projection of the storm centre is about 15 per cent. of the cloud height away from the rod. There are no ground hits closer to the rod than four times its height for the extremes given in Fig. 14. (Tables XIV and XV.)

Division of Hits between Rod and Ground for Different Heights of Rod.—The division of hits between a lightning rod and ground, when the rod is located directly under the storm centre, is shown in Fig. 16. When the rod has zero length, 100 per cent. of the hits, of course, must strike the ground. When the height of the rod is 1.1 per cent. of the cloud height, the division of hits is equal, while all of the strokes go to the rod when it is

TABLE XIV.

Area Protected by Lightning Rod.

(Rod Directly under Storm Centre.)

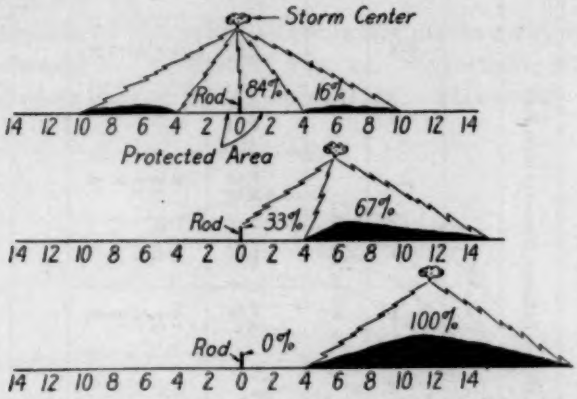
Gradually Increasing Voltage Combined with Impulse.

Height of Rod.		Total Strokes p. c.	Strokes to Rod p. c.	Strokes to Ground p. c.	Distance Nearest Ground Hit to Rod.	Dist. Nearest Hit. / Height of Rod.	Number of Hits at Different Distances from Rod.										All Others.
							Inches.										
							0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	
Inches.	Per cent. Cloud Height.						P. C. Cloud Height.										
							0 — 2.47	2.47 — 4.94	4.94 7.40	7.40 9.90	9.90 — 12.3	12.3 14.8	14.8 — 17.3	17.3 — 19.6	19.6 — 22.2	22.2 — 24.7	
0	0	100	0	100	0.31	——	3	11	14	18	14	15	8	11	2	3	1
.12	.31	100	7	93	0.62	5.0	1	5	13	19	17	16	11	6	3	1	1
.25	.62	100	16	84	2.12	8.5	0	0	9	15	20	16	11	6	3	1	0
.50	1.23	100	62	38	3.12	6	0	0	0	3	5	10	8	5	3	1	3
.75	1.85	100	84	16	4.5	6	0	0	0	0	1	3	4	3	2	1	2
Impulsive Discharge.																	
.75	1.85	100	92	8	3	4	0	0	0	1	2	1	1	1	1	1	0

Rod directly under storm centre—A point on flat cloud—Rod needle on smooth surface—Distance from ground to storm centre—40.5 inches = Height of cloud—approximately 500 strokes per each rod.

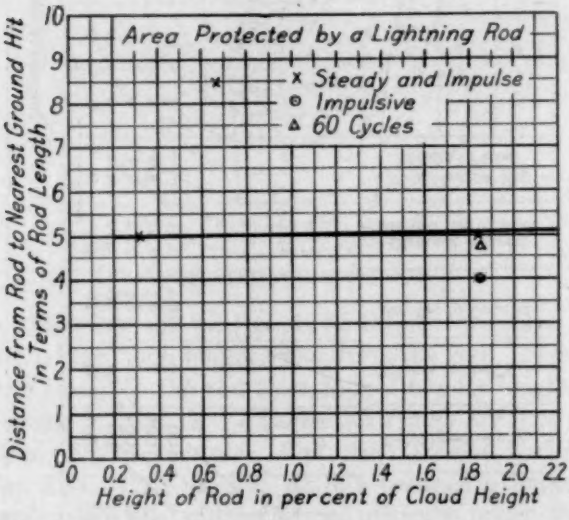
about 2.5 per cent. of the cloud height. Over this range, the ground was never hit nearer to the rod than four times its height.

FIG. 14.



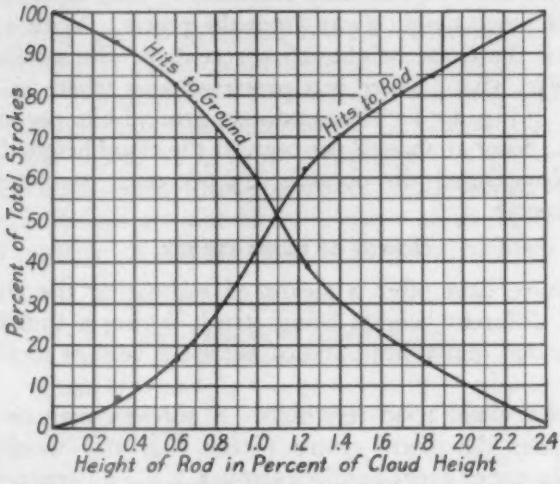
Protected area and distribution of hits between rod and ground for different positions of storm centre.

FIG. 15.


Area Protected by a Lightning Rod
Steady and Impulse
Impulsive
60 Cycles
Distance from Rod to Nearest Ground Hit in Terms of Rod Length
0 1 2 3 4 5 6 7 8 9 10
0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 2.2
Height of Rod in per cent of Cloud Height

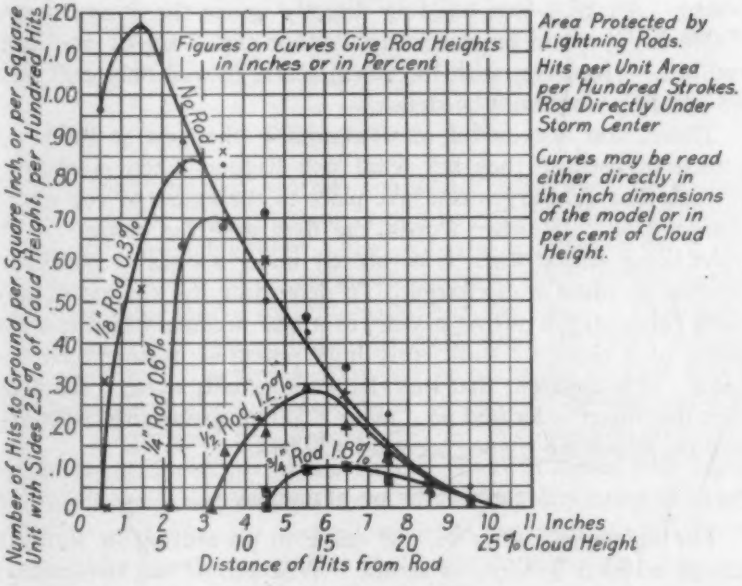
Hits per Unit Area under a Storm Cloud.—Fig. 17 shows the ground hits per unit area at various distances from rods of different heights. The rods are directly under the storm centre. With rods of zero height, 1 per cent. of the hits per unit area

FIG. 16.



Division of hits between rod and ground for different heights of rod.

FIG. 17.


Figures on Curves Give Rod Heights in Inches or in Percent
No Rod
1/8" Rod 0.3%
1/4" Rod 0.6%
1/2" Rod 1.2%
3/4" Rod 1.8%
Number of Hits to Ground per Square Inch, or per Square Unit with Sides 2.5% of Cloud Height, per Hundred Hits
Distance of Hits from Rod
11 Inches
25% Cloud Height
Area Protected by Lightning Rods.
Hits per Unit Area per Hundred Strokes. Rod Directly Under Storm Center
Curves may be read either directly in the inch dimensions of the model or in per cent of Cloud Height.

occur directly under the storm centre. The number of hits per unit area decreases rapidly until there are no hits at about 25 per cent. of the cloud height away from the centre. With a rod 0.6 per cent. of the cloud height, 16 per cent. of the strokes strike the rod (Fig. 16). There is a protected area where no ground hits occur. (Fig. 17.) The maximum ground hits per unit area, .7 per cent., occur at about 8 per cent. of the cloud height from the centre. No ground hits occur at 25 per cent. of cloud height from the centre.

CHANCE OF BEING STRUCK.

The above data offer a means of estimating the chance of objects of different heights being struck during a thunderstorm when the cloud is overhead and of sufficient voltage to discharge to earth.

Assume a cloud 1000 feet high. A six-foot man on a plane directly under the storm centre (from Fig. 16) would be hit fifteen times out of every hundred strokes, while a twenty-five-foot building would be hit every time. A man flat on the ground (from Fig. 17) would be struck about once for every hundred strokes. An 18.5-foot building directly under the storm centre (Table XV) would be struck eighty-four times out of one hundred hits. However, with the storm centre moved only 296 feet, this building would not be struck.

These data are useful in determining the best methods of protection, because they tell what will happen when conditions are such that discharges can take place to the house or rod under consideration. In other words, the data give the chance of an object being struck when it is directly under a cloud at sufficient potential to cause a discharge. To determine the chance of any object being struck during a year, it is also necessary to know the chance of a cloud of sufficiently high potential passing over the object. It is apparent that this chance is usually quite small even when the object is located on a plane. When mountains, hills and trees are added the chance becomes still less.

PROTECTION OF BUILDINGS.

The lightning rod is of real value in preventing or limiting damage when a building is struck. Whether or not it increases the chance of being struck depends upon circumstances. It is rather doubtful if it often does, as a chimney, grounded gutter,

or water pipe may be sufficiently conducting to determine the direction of the stroke.

In deciding upon a lightning rod the economic factor or the cost of protection must be considered in connection with the probability of being struck. It seems that the best results can be obtained with plain inconspicuous rods. Ornate rods or rods with special points appear to have no advantage. A grounded metal roof would seem almost ideal protection. Rods should be installed so that side flashes are not likely to occur to conducting objects inside or outside of the building. When a building is in an

TABLE XV.

Area Protected by Lightning Rod.

(Rod Not Directly under Storm Centre.)

Gradually Increasing Voltage Followed by Impulse.

Height of Rod.		Distance from Projection of Storm Centre.		Total Strokes.	Strokes to Rod.	Strokes to Ground.	Distance Nearest Ground Hit to Rod.	Ratio Distance Nearest Hit to Height of Rod.
Inches.	P.C. Cloud Height.	Inches.	P.C. Cloud Height.					
·75	1.85	0	0	100	84	16	4.5	6
·75		3	7.4	100	—	—	7.2	9.5
·75		6	14.8	100	33	67	3.7	5
·75		12	29.6	100	0	100	3.7	5

Height of Cloud—40.5″

exposed position and storms frequently pass over it, a more elaborate outlay for protection would be justified than in the case of an unexposed building. For instance, a building on a cliff over a valley followed by storms would be in much greater danger from lightning than a building located in the valley. This would be especially so if connections were made from the upper building to water level. Lightning rods can be arranged to give almost ideal protection when the expense is warranted. In the case cited above, a lightning rod located on the cliff would give good protection to buildings in the valley. It is probable that except for buildings in exposed positions and for special cases as magazines or oil tanks, the cost of even an inexpensive rod is not warranted from the standpoint of the cost of insurance.

Sparks Inside of Metal Tanks.—Tests have been made to determine if it is possible to cause sparks inside of metal tanks

TABLE XVI.

Area Protected by Lightning Rod.

(Rod Directly under Sphere Cloud.)

Height of Rod.		Total Strokes p. c.	Strokes to Rod p. c.	Strokes to Ground p. c.	Distance of Nearest Ground Hit from Rod.	Distance Nearest Hit / Height of Rod.	Number of Hits at Different Distances from the Rod.										All Others.
							Inches.										
							0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	
Inches.	P. C. Cloud Height.						P. C. Cloud Height.										
							0 2.92	2.92 5.84	5.84 8.68	8.68 11.7	11.7 14.6	14.6 17.6	17.6 20.4	20.4 23.4	23.4 26.4	26.4 29.2	
60-cycle voltage—cloud 25 cm. sphere—3.42 inches high.																	
¾	1.85	100	81	19	3.5	4.7	0	0	0	1	2	2	2	4	4	3	1
Impulse voltage.																	
¾	1.85	100	64	36	2.75	4.0	0	0	0	2	5	8	8	5	3	2	3
Steady voltage with impulse.																	
¾	1.85	100	74	27	3.75	5.0	0	0	0	1	3	8	4	4	4	1	1

25 cm. sphere. 34¼ inches above plane.

TABLE XVII.

Area Protected by Lightning Rods.

Hits per Unit Area.

(Rod Directly under Storm Centre.)

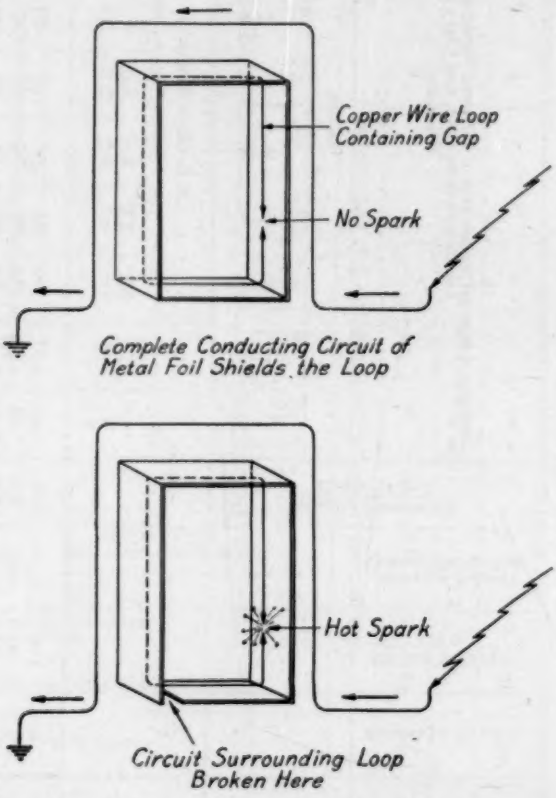
Gradually Increasing Voltage Followed by Impulse.

Height of Rod.		Total Strokes p. c.	Strokes to Rod p. c.	Strokes to Ground p. c.	Distance Nearest Ground Hit to Rod.	Distance Nearest Hit. / Height of Rod.	Number of Hits per Square Inch at Different Distances from Rod—or Hits per Square with Sides 2.5 p. c. of Cloud Height. (Distance.)									
							Inches.									
Inches.	P. C. Cloud Height.						0—1	1—2	2—3	3—4	4—5	5—6	6—7	7—8	8—9	9—10
							P. C. Cloud Height.									
							0–2.47	2.47–4.94	4.94–7.40	7.40–9.90	9.90–12.3	12.3–14.8	14.8–17.3	17.3–19.6	19.6–22.2	22.2–24.7
0	0	100	0	100	0.31	—	.96	1.17	.89	.83	.50	.43	.20	.23	.38	.05
.12	.31	100	7	93	0.62	5.0	.31	.53	.83	.86	.60	.46	.27	.13	.056	.017
.25	.62	100	16	84	2.12	8.5	0	0	.63	.68	.71	.46	.34	.13	.056	.017
.50	1.23	100	62	38	3.12	6	0	0	0	.14	.18	.29	.20	.11	.056	.017
.75	1.85	100	84	16	4.50	6	0	0	0	.035	.087	.098	.063	.038		.017

Height of Cloud—40.5 Inches.

or cans by direct stroke or by electromagnetic induction or electrostatic induction. It has not yet been possible to obtain sparks between points within a completely closed metal tank. Under certain conditions small sparks have been obtained by electromagnetic induction between points in partly enclosed metal structures

FIG. 18.



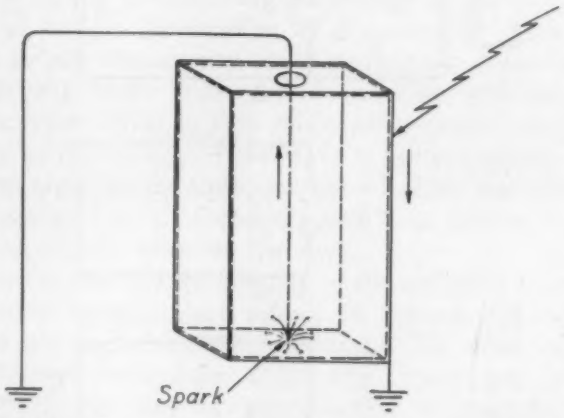
as illustrated in Fig. 18. Sparks are readily obtained within tanks from a *grounded conductor* brought in from the outside as illustrated in Fig. 19. The wire is slightly insulated from the tank by oxide or otherwise. The spark occurs by electrostatic induction or when either the wire or tank is struck. This is interesting in that sparks may be obtained from a grounded conductor.

The above experiments have a practical value because they

show the danger of any lead in conductors to oil tanks or magazines. They also illustrate the importance of having no projections within a tank. For instance, a metal rivet insulated from a tank in oxide, might cause a sufficient spark to ignite gases within the tank. Grounded gauge chains could readily cause internal sparks.

Fires by Lightning.—It is quite possible to cause fires by lightning by sparks between isolated metal parts even when direct strokes do not occur. Some model bales of cotton were placed

FIG. 19.



Method of obtaining a spark from a grounded conductor within a grounded tank.

under the model cloud. It was found that the cotton could be ignited by sparks electrostatically induced between the metal bonding strips.

Artificial Lightning.—The author's lightning generator and various destructive effects produced by it were described in a lecture before the Institute last November. This lecture will be found in the January, 1924, JOURNAL. It may be well to mention the chief characteristics of this generator here.

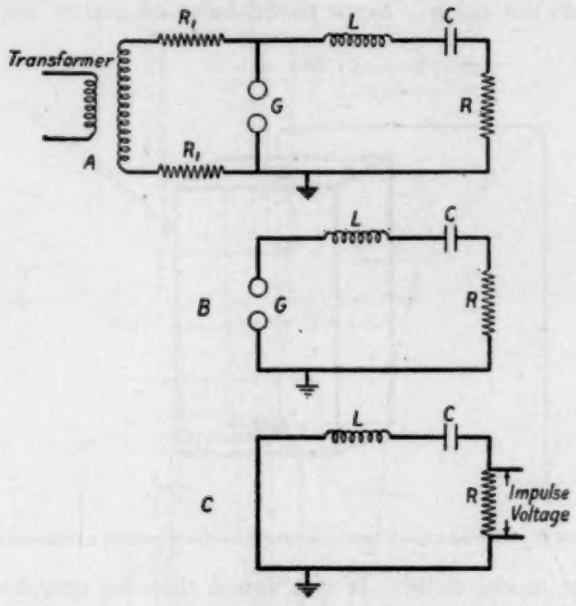
This generator supplies 2,000,000 volts above ground with an energy of 2000 watt seconds. The power may be several million kilowatts. The voltage is thus about 2 per cent. of a natural lightning stroke and the energy about two-hundredths per cent. The character of the discharge is similar to natural lightning.

The voltage and energy are of the same order as the voltage and energy resulting on transmission lines from natural lightning.

The destructive effects are similar to those of natural lightning.

The generator circuit is shown in Fig. 20 *A;* its operation is as follows: The gap is set at some desired voltage. The transformer voltage is increased until discharge occurs. At that

FIG. 20.



Impulse generator circuit.

instant the condenser C is charged up to a voltage corresponding to the gap setting. There is very little drop in the resistance R_1 since the sixty-cycle charging current is relatively small. A dynamic arc forms at G and holds. This acts as a switch and the condenser discharges through the known inductance, R and the arc. R is a very small fraction of R_1. For the large impulse current R_1 is practically equivalent to infinity. The circuit producing the impulse is shown in Fig. 20 B, or is, in effect, that shown in 20 C. The condenser discharging through the known resistance and inductance causes a transient current that can be readily calculated. The current produces an impulse voltage drop

across R. This is the impulse voltage used in the test. It makes high lightning voltages possible because it is excited at sixty cycles a.c. and does not require a rectifier or static machine. Its only *present* limit is the available a.c. voltage supply.

Voltage waves similar to the current waves in Fig. 4*a*, or to the line voltage wave in Fig. 4*b*, are readily produced by varying R, C and L. In fact, impulses closely corresponding to single half cycles, of sine waves of 50 to over a 1000 kilocycles, have been studied, as have impulses of steep front but long duration. The effect of these waves on insulation, corona, spark discharge, etc., can be found in the *Transactions of the A. I. E. E.*[17]

The equations for obtaining the voltage and current are given below and involve the solution of a quadratic. This equation does not include the capacity of the test piece C_1, which is placed across R (Fig. 20). It is generally possible, with the approximate sine wave setting to keep this capacity small enough so that the shape or the voltage of the wave is not appreciably different from that given by the equations below. This was generally so in the investigation. C_1 frequently may be as high as 10 per cent. without appreciably affecting the wave.

When the effect of the capacity of the test piece is considered, the resulting equation is a cubic. In general, the equation is increased one degree for every addition. The effect of capacity C_1, resistance, inductance, connecting leads, was considered mathematically as well as theoretically. It presents no great difficulty. The equation requires too much space to give here. C_1 tends to decrease the steepness of the wave or increases the time for reaching maximum. It first tends to increase the maximum voltage and then decrease it as C_1 is increased in value.

Equations for Calculating Impulse Generator Waves.

Trignometric (Oscillatory) Case: Maximum Voltage:

$$e_{max.} = \frac{2ER}{q}\,\varepsilon^{-\frac{R}{q}\tan^{-1}\frac{q}{R}}\sin\tan^{-1}\frac{q}{R}$$

Where $e_{max.}$ = the maximum of the impulse voltage.

E = the maximum of the 60-cycle voltage across the gap "G" (or the condensers at $t=0$).

[17] F. W. Peek: "The Effect of Transient Voltages on Dielectrics," *A.I.E.E. Trans.*, Vol. xxxiv, p. 1857. "Lightning," *G. E. Rev.*, July, 1916.

R = the resistance of the water tubes.

$$q = \sqrt{\frac{4L}{C} - R^2}$$

$\varepsilon = 2.718$.

Time to Reach a Maximum:

$$t = \frac{2L}{q} \tan^{-1} \frac{q}{R}$$

Voltage at Any Time t:

$$e = \frac{2E}{\sqrt{\frac{4A}{B^2} - 1}} \varepsilon^{-\frac{BT}{2A}} \sin \frac{Bt}{A2} \sqrt{\frac{4A}{B^2} - 1}$$

Where $A = C \times L$

$B = C \times R$

$\varepsilon = 2.718$.

C expressed in farads.

R expressed in ohms.

L expressed in henrys.

t expressed in seconds.

Equations for Calculating Impulse Generator Waves.

Logarithmic (Impulse) Case: Maximum Voltage:

$$e_{max.} = \frac{ER}{S}\left[\left(\frac{R+S}{R-S}\right)^{-\frac{R-S}{2S}} - \left(\frac{R+S}{R-S}\right)^{-\frac{R+S}{2S}}\right]$$

Where $e_{max.}$ = the maximum of the impulse voltage.

E = the maximum of the 60-cycle voltage across the gap "G" (or the condensers at $t = 0$).

R = the resistance of the water tubes.

$$S = \sqrt{R^2 - \frac{4L}{C}}.$$

Time to Reach a Maximum:

$$t = \frac{L}{S} \log_\varepsilon \left(\frac{R+S}{R-S}\right)$$

Voltage at Any Time t:

$$e = \frac{E}{\sqrt{1 - \frac{4A}{B^2}}}\left[\varepsilon^{-\frac{Bt}{2A}\left(1 - \sqrt{1 - \frac{4A}{B^2}}\right)} - \varepsilon^{-\frac{Bt}{2A}\left(1 + \sqrt{1 - \frac{4A}{B^2}}\right)}\right]$$

Where $A = C \times L$

$B = C \times R$

$\varepsilon = 2.718$.

C expressed in farads.

R expressed in ohms.

L expressed in henrys.

t expressed in seconds.

The author acknowledges the assistance of Mr. W. L. Lloyd, Jr., and others in the High Voltage Engineering Laboratory.

MERCURY VAPOR PROCESS.*

BY

W. L. R. EMMET, Sc.D.

General Electric Company.

THE process described in this lecture has been undergoing experimental development for some years, and, for the last year, has been operating in a large experimental installation in a plant of The Hartford Electric Light Company.

The purpose of this process is to obtain improved thermodynamic efficiency from fuel through the use of a greater temperature range than is practicable with steam.

While the efficiency of thermodynamic processes is limited by many peculiarities of the substances used, they are generally dependent upon the temperature range and, since with steam turbines we work effectively down to the lower temperature limit as established by our cooling water, we must look for substantial gains to the use of higher maximum temperatures than have been used with steam. With this end in view, higher and higher steam pressures have been used and superheating and reheating of steam to the maximum degrees possible have been considered.

Water boils at 212° F., has a pressure of 3200 pounds per square inch at 706° F., and cannot exist as a saturated vapor at any higher temperatures. As it approaches this critical temperature its latent heat of vaporization progressively diminishes and the heat in the liquid increases. These peculiarities and temperature limitations introduce certain practical difficulties in the effective use of steam to high temperatures, in addition to those which are incident to the excessive pressures which must be handled.

Mercury boils at 677° F. with atmospheric pressure, and at 706° has a pressure of only five pounds above the atmosphere. At 900° F. its pressure is only eighty pounds above the atmosphere. Throughout this entire range, its heat of evaporization only varies slightly and the heat in the liquid is relatively very small, which qualities excellently adapt it to thermodynamic purposes.

* Address delivered Thursday, September 18, 1924, on the occasion of the celebration of the centenary of the founding of The Franklin Institute.

In this process, mercury is vaporized in a boiler from which it is conveyed in a pipe to a turbine which drives a generator. On exhausting from this turbine at a vacuum pressure, it delivers its heat of vaporization to tubes in which high pressure steam is thereby generated. This steam can be applied to any purpose. After condensing on this steam-making surface the liquid mercury runs back by gravity into the boiler where it is again vaporized. With a view to cost reduction, the boiler is designed to operate on a very small volume of mercury and the total quantity may be vaporized nine or ten times in an hour. The furnace gases, after passing through the mercury boiler, are carried through a heater to raise the temperature of the returning liquid mercury, then they pass through a superheater for the steam made, and then through an economizer for heating feed water, so that they arrive at the stack as cool as in a simple steam process with similar arrangements.

A paper entitled "The Emmet Mercury Vapor Process" has recently been contributed to the American Society of Mechanical Engineers and from this the following description of the Hartford equipment is quoted:

THE HARTFORD INSTALLATION.

"The equipment at Hartford was designed to operate with 35-lb. gauge pressure on the mercury boiler, to deliver about 1800 K.W. from the mercury turbine, and to make steam at 200-lb. pressure with about 100 degrees of superheat. The furnace gases pass in order through the mercury boiler, a mercury-liquid heater, a steam superheater, and a feed-water heater. It would be more economical to substitute for the last-named device an air heater, since it would put this residuum of heat into the mercury instead of into the steam. The feed heat would then be accomplished by bleeding the steam turbine.

"The mercury vapor formed in the boiler passes through a governing and emergency valve to the turbine, the single wheel of which is overhung on the end of the generator shaft and operates in the condenser space. Two safety valves are arranged to bypass the vapor into the condenser if the governor causes its valve to close, so that the mercury vapor continues to be condensed and to make steam whether it is passing through the mercury turbine or not. The shaft passes through a packing between the generator and the turbine wheel and this is sealed by mercury vapor above atmospheric pressure. The outward leakage from this packing is sucked into a cooler where it is all condensed and returned to the system.

"The discharge from the turbine wheel is delivered directly against the condensing surface which consists of dead-ended tubes hanging vertically from

a cylindrical steam and water drum, to which they are attached by rolling and also arc welding.

"The condenser shell and all the pipes and containers which carry mercury are put together by welding. From the condenser the liquefied mercury runs through a sump to the mercury heater and boiler by gravity.

"On the side of the condenser shell a large blowout diaphragm is provided which communicates to the stack and will give way if, through escape of steam or water or other cause, the pressure in the condenser should begin to rise unduly.

"The mercury boiler at Hartford is made up of fire tubes, the lower two-thirds of which are hexagonal with slightly convex faces. These are nested together like a honeycomb, and for each seven tubes a space is left for a duct which returns the circulating liquid. This liquid rises and the vapor forms in clearances between the tubes at the corners. The use of such tubes in a mercury boiler was proposed by Mr. B. P. Coulson, the author's assistant. The upper round part of the tubes acts as superheating surface and the vapor is delivered with a little superheat, which is desirable for the reason that it probably tends to prevent cutting of the turbine blades—of which there has been none at Hartford, although a slight amount was observed in former turbines.

"This equipment has been run experimentally for several months. Few troubles have been experienced and nothing of a serious nature. It has delivered power to the circuits for about 800 hours. The highest load carried has been 1500 kilowatts, and the load carried most of the time has been 1200 kilowatts. There has been some uncertainty as to the safe capacity of the boiler and, since experience with continued operation has been the most important need, it has been thought best to avoid risk of any possible serious trouble. The conditions of running cannot be considered commercial, but the results secured give a very good indication that commercial results are not difficult of attainment.

"As soon as certain boiler experiments now in progress are satisfactorily completed, it is proposed to build a new boiler of a different type for the existing Hartford installation. This boiler we propose to adapt for a pressure of 70-lb. gauge, the design pressure of the present boiler being 35-lb. gauge. We also intend to build a new three-stage turbine instead of the one-stage turbine now used. When these changes are made it is hoped that this installation will be representative of types which can be repeated indefinitely on a large scale and with such resultant economies as have been outlined in this paper."

If this process can be developed to a thoroughly workable condition, the economies obtainable are very high. With steam conditions equivalent to those in the best existing power stations, the gain in output per pound of fuel should be from 50 per cent. to 60 per cent., and, as compared with the possibility of the very high-pressure installations contemplated, the gains should still be very large. The following table gives a comparison with expected results of the 50,000 K.W. high-pressure turbine unit which is to be installed at Chicago:

Heat Distribution per K.W. Output.

50,000 K.W. Turbine.

Expected Normal Monthly Operation.

Steam Press., 550-lb. G.; Temp., 750° F.; Reheat Press., 115-lb. abs.; Reheat Temp., 700° F.; Exhaust at 0.75 in. of hg. abs.

Compared with Mercury Steam Combination.

Mercury generating unit having an efficiency of 70 per cent. and operating at 70-lb. G. press.; steam turbine being the same with same conditions but without reheating.

	Steam Alone.		Mercury and Steam.
Heat from fuel:			
Heat to normal boilers	14,004 B.t.u.,	93.4 p.c.	
Heat to reheater	996 B.t.u.,	6.6 p.c.	
	15,000 B.t.u.,	100.0 p.c.	11,000 B.t.u.
Heat from turbine returned to boilers by heaters	2,320 B.t.u.		
Heat distribution:			
Banked fire and standby losses	1,800 B.t.u.,	12.0 p.c.	1,305 B.t.u.
Stack loss	1,443 B.t.u.,	9.6 p.c.	1,046 B.t.u.
Other boiler losses	812 B.t.u.,	5.4 p.c.	585 B.t.u.
Auxiliary power	670 B.t.u.,	4.5 p.c.	487 B.t.u.
Net heat to steam jets, etc.	35 B.t.u.,	0.2 p.c.	21 B.t.u.
Heat to circulating water	6,649 B.t.u.,	44.4 p.c.	3,983 B.t.u.
Generator losses	178 B.t.u.,	1.2 p.c.	103 B.t.u.
Electrical energy from generator	3,413 B.t.u.,	22.7 p.c.	1,992 B.t.u.
		100.0 p.c.	
Mercury generator losses			57 B.t.u.
Electrical energy from mercury generator			1,421 B.t.u.
Total electrical energy 1 k.w. hour 3413 B.t.u.			3,413 B.t.u.

In these figures the auxiliary load has been taken as proportionate to the fuel burned, which assumption is unfavorable to the mercury process, since the load of circulating air feed and hot well pumps are all proportionate to the steam load and not to the fuel burned. The mercury apparatus adds no auxiliary but an air pump which takes very little power.

It should here be observed that the reheating of steam which is important to economy in the steam cycle, and which involves a great deal of expense and difficulty, is not required in the mercury steam combination.

From this table, it will appear that the mercury steam combination should give a gain in output per pound of fuel of 36 per cent. over this very advanced steam application. In this comparison, the figures bear a positive relation to each other and there can be no appreciable error unless it be in the assumption as to the efficiency of the mercury turbine which would seem to be conservative.

THE TREND AND PURPOSE OF MODERN RESEARCH.*

BY

HARRISON E. HOWE.

Editor, *Industrial and Engineering Chemistry.*

KNOWING something of the long line of distinguished scientists who have addressed The Franklin Institute during the past one hundred years and the considerable number of important discoveries that have been announced in the course of these lectures, I am somewhat embarrassed at my inability to bring you details of some original research or discovery of my own. But my work for several years has had to do more with finding ways and means for the support of research and encouragement for those engaged in such important activities, as well as with an effort to secure for science an ever-increasing circle of appreciative friends among our intelligent laity and industrial executives. This has involved maintaining points of contact with the natural sciences, more particularly chemistry, and so it seemed worth while to devote this hour to taking stock and considering together whither we seem bound.

All ages have their fads and fancies, in science as well as in fashions, and although science shifts its emphasis slowly and without regularity, nevertheless, we find one theory after another holding the centre of the stage. With the development or unfolding of science from the days when the composition of the earth and its envelope was expressed in terms of four elements, down through the discovery of our modern atomic list, to the present time, when many hold all matter to be ultimately one or two forms of energy, there has come about an almost incomprehensible diversity of theories and of research activities. The chemist may still be fairly said to seek elixirs of life and the transmutation of metals, but unlike the alchemist, who had these as his only object, the chemist touches our modern life at so many points as to require him to specialize within more and more narrow limits. However, he has not reached the point where he must confine himself to so special an interest as the medical graduate who told his friend that he would specialize upon the ear, but he had not decided whether it should be the right or the left ear.

* Presented at the Stated Meeting of the Institute held Wednesday, November 19, 1924.

If modern chemistry as represented by all its specialists is united upon any one problem, it is that all-important one of the ultimate constitution of matter. Little by little some of the complex substances of nature have been taken apart, but we have not yet completely torn down the structure to its unit building blocks, and until we do we cannot reassemble these blocks in a structure more to our liking, nor can we know how to fit blocks of all sizes, shapes, and colors into our building plan. We have been following a stream to its source and have mapped out several branches, each a subdivision of its predecessor, but we have not yet come to those damp patches of earth which are the real source. Until then, we cannot expect to direct the stream effectively in a predetermined direction to serve our needs.

To many it seems that the ordinary work of chemistry has been accomplished. So many compounds have been taken apart and put together again that we should have accumulated the necessary preliminary training and experience to prepare for the early discovery of really great things. The progress report that can be made on the effort to separate a single molecule from the large crowd and so study its mechanism and behavior is encouraging. Modern conceptions of atomic structure not only serve to explain many of the phenomena uncovered through present-day research, but also emphasize the difficulty of the problem. Thus we are informed that, should we succeed in devising apparatus to enable the hydrogen or the helium atom to be seen, we could not see it, for it travels at too great a speed. The work of such men as Bohr, Lewis, and Langmuir has succeeded in establishing many facts relative to organic, inorganic, molecular, and atomic structure. The Braggs, father and son, Wyckoff, Hull, Davy, and the group utilizing the X-ray have already established many facts regarding space structure, and this work has progressed to the point where it has a practical application in carbon manufacture and in metallurgy. The methods for studying the electron as devised by Millikan and others are indicative of the marvellous technique characterizing our research to-day, making possible actual observations and experiments by which to prove our latest electronic theories.

To those who fail to keep pace with the day-by-day work, accounts of such achievements come as revelations indeed. Shortly after becoming a graduate student, circumstances led me into

industrial work at a point quite removed from scientific influences. As a student, no one had endeavored to impress me with the value of membership in scientific societies, nor had journals been recommended to me as important equipment in pursuing my chosen work. Of course, I soon lost contact with what research was doing, and I have never forgotten my reaction toward an instructor who came from a university some three years later to give a high school commencement address. The ease with which he discarded the atom as the ultimate unit of matter was a shock to me and at the time gave me the impression that the lecturer was merely trying to overwhelm the townspeople.

Experimental work with the infinitely small, which to-day is in progress in nearly every laboratory, gives us ample reason to believe in eventual success for those who are intent upon unravelling nature's innermost secrets. Having established many truths with respect to atomic and molecular structures, many of our leading minds are working upon the problems incident to surface phenomena, catalysis, and oriented structures as possible explanations for the erection of enormously complex structures from the simplest materials. Just as the dividing line between organic and inorganic materials has grown less and less distinct, so also may we soon have difficulty in distinguishing between crystal and colloidal structure, and may find the space lattice with which crystal structure is being determined also applicable to colloids.

Our day is unique in the extent to which scientists are cultivating the borderland between the major divisions of science. I need hardly remind you of what has been accomplished in geophysics, astrophysics, and biophysics. Physical chemistry, developed rapidly as a specialty, has grown in importance until it bids fair to dominate the entire chemical field. Its laws and theories are being everywhere applied. Methods peculiar to physical chemistry find a place in all research laboratories, and many of our most remarkable recent achievements in industry must be credited to men well grounded in its principles. Biochemistry affords opportunities unsurpassed by any science and worthy of any genius, dealing as it does with the most complex substances; the problem is further complicated in that reactions must be interpreted almost in terms of life itself. Here, too, the infinitely little is the important thing; and while one group concerns itself with the isolation and identification of these elusive bodies, another

addresses its attention to the far-reaching problem of the relation to life of these unseen factors. Enough has been demonstrated, for example, regarding the place in nutrition of those food accessory substances called vitamins, to make it desirable to know whether foods believed to be devoid of them can be endowed with the potentialities of foods known to have the properties so profoundly influencing body growth, repair, and maintenance. Until recently it has been thought that this could be done only by isolating the vitamin in question and then preparing it in concentrated form for addition to such materials as milk reconstituted from dry skim milk and neutral cocoanut fat. Once isolated, there is the possibility of synthesis, followed by commercial production at favorable costs. Now comes the interesting report that fats such as cottonseed oil may be made to take on the virtues of vitamin-A-bearing fats, such as cod-liver oil, by exposure to ultra-violet light. Perhaps we shall find that, after all, vitamins are not chemical compounds, but forms of energy, and that they fit into the modern theories of atomic structure.

Concurrently, hormones—the messengers—are objects of intense study on the part of the biochemist and the physiological chemist. The reward is great. Many human ills are due to deficiencies in metabolism, just as others may be traced to deficiency in nutrition. To what extent are these metabolic ailments due either to the lack of hormones or their failure to function properly? What is the chemistry of their action? What is the function of the many ductless glands, chemically speaking? Answers to such questions will mean advances in the application of chemistry through medicine, which may easily surpass those that have been made with the help of insulin, one of the first recruits in this type of warfare upon disease. It may even become possible profoundly to influence mental and physical growth or to predetermine sex, a power requiring such wisdom in application as to make it dangerous.

The use of apparatus usually identified with some other branch of science for the work in hand is another encouraging sign in modern research. Consider what the adaptation of electrical devices has meant to chemistry, and how the microscope in its various forms is giving us a new system of analysis, both qualitative and quantitative, destined to become a most important method. The determination of constants is so necessary, in

the case of compounds, that any method enabling such work to be done with accuracy on minute samples at once takes a place in the front rank of the tools with which we carry on our work. One unfamiliar with the possibilities of micro-analysis and in the habit of requiring substantial quantities of an unknown for examination, finds it difficult to appreciate at first what minute samples can be made to yield reliable results.

Another broad field in which we find applied any device promising useful service is that of testing materials. Many look upon this as routine, whereas the development of testing methods calls for research of a high order. X-rays to detect faults in rolled, cast, or forged metal, motion photomicrography in ascertaining to what extent metal in service has become fatigued, and the problem of thorough testing without destruction of the sample, as well as the possibility of testing structural members in place, are examples of what is involved. A realization of the limits upon research imposed by apparatus has brought many important contributions from men gifted in this specialty. It will be recalled that Abbé, in appealing for new optical glasses, called attention to the arrested state of development in science and industry, awaiting instruments impossible to construct without new types of lenses. The great impetus given to microscopy, astronomy, photography, and applied optics, when the new glasses became available, is a matter of history, and much that has been accomplished in chemistry, medicine, physics, and other natural sciences could not have been done but for this work, which began to bear fruit in the early nineties. No less does research in chemistry depend in a large measure upon the glass, porcelain, alloys, and optical glass available to-day. We are beginning to use the motion picture as a piece of laboratory apparatus, and occasionally new substances are devised which extend the possibilities of our work. The synthetic resins, liquefied gases, and refractories composed of materials made in the electric furnace rather than by nature's tedious process are examples. When materials difficult to produce, even in small quantities, suddenly become available in sizes and shapes useful in laboratory procedure, new fields are at once opened. Thus the appearance within the last year of clear fused quartz in rods, discs, sheets, and other large masses may be expected to lead to new discoveries with the aid of the telescope, the microscope, and in the treatment of disease.

Chemistry is a useful science and has performed its share of the work throughout our scientific and material progress. Chemistry began by taking apart or dissecting substances of nature, that we might know with what we have to deal. Then came a period of stimulation when science was applied to increase yields, as in agriculture, and this application must continue. Now, having worked out many theories, we are in an age of structural chemistry, where we are concerned principally with synthesis and the conservation of natural resources through their efficient utilization. Chemistry, while continuing to offer the utmost attractions to the researcher, the philosopher, and the dreamer, is at the same time a science at work. As industry after industry becomes convinced that chemistry can be made helpful to it, more and more demands are made upon research, for there are still too many questions that cannot be answered from the data in hand nor by the work in progress. It is common knowledge among chemists that it is a simple matter to make rapid progress in an industry where chemists have had no previous opportunity, because widely known principles may be applied to advantage where empirical methods have previously held sway. But the time soon comes when experience is insufficient, when new relationships must be understood and new data obtained before progress can be continued. The man who applies himself to fundamental work need have no fear that his results will not be useful. There is need for all the truth we can know. The danger is more likely to come from imperfect accounts of what has been done, of why and how it was undertaken, and lack of a clear statement of the facts established and their relation to other known facts. It is often surprising to find how careful an investigator has been in his work upon carelessly chosen material, and how greatly the value of the results could have been increased had the history of the sample been clearly established.

The pooling of resources upon research problems of major importance is one of our most encouraging signs. With some forty trade associations supporting research on a scale ranging from a research fellow or two to the maintenance of association laboratories, we may properly expect big things. This work, sustained in truly American fashion without recourse to governmental funds, nevertheless enjoys coöperation with the many splendid bureaus of federal, state, and municipal governments.

If such trade association activity does no more than dispel the myth which surrounds most trade secrets, we will gain much.

When certain industrial concerns undertook investigations in pure science on their own account, another important step was taken in research. This has been followed by an interchange of the by-products of industrial research, a willingness to state problems of interest, and coöperation between the industries and universities that is full of possibilities.

We find, then, an increasing number of trained men and women in that type of research known as pure science or fundamental work. It is usually undertaken without thought of immediate application and primarily that bits of truth may be established. The trend of research here is toward establishing the constitution of matter, the mechanics of the molecule, the structure of the atom, and the laws to which surface phenomena conform. A great number of relationships between elements and compounds under a wide variety of conditions are being established, and the by-products of this research are being put to work in the industries.

Another group of equal ability is busy applying known facts to industry. This work is equally difficult and important. So far as the general public is concerned, the results are of more immediate interest and can be understood and better appreciated. But no one should forget that the foundations rest on some two hundred years of accumulated knowledge and established facts. This industrial research is truly a service activity. Whatever it may mean to its employer of the moment, it can nearly always be discussed in terms of economics and in some type of saving to the consuming public. No attempt will be made here to instance all the important trends in such research. I do not pretend to have such complete information and I am sure that you do not have the patience to hear so long a list discussed. A few examples will suffice to show how we are gradually but surely getting out of old ruts, revising our methods, and steering a course that seems certain to enable us to reach our objective.

For many years conservation of natural resources has been preached, and it is not surprising that with a seemingly inexhaustible supply the warning has fallen for the most part on deaf ears. To-day we begin to feel the pinch, not merely because we have increased our demands, but because the costs of transportation,

manufacture, and distribution have risen so rapidly that, even where abundant raw materials are concerned, their influence upon the ultimate price of a given article is small. In other words, while a given structural steel member may cost somewhat more to manufacture than a few years ago, it costs much more to transport it, and a great deal more to place it than formerly. The replacement of such a structural member is therefore far more serious than was once the case. When the plumbing in your house fails, it is not the cost of the new pipe that bankrupts you; it is the cost of putting it in place. We therefore seek means for prolonging the service life of materials. The corrosion problem in consequence is beginning to receive real scientific attention. The methods employed until lately to determine materials best suited for a given purpose have not been useful in disclosing the underlying causes of corrosion. Until we know whether it is due to some form of electrolysis or how to provide a self-healing film, we cannot expect the utmost success in producing non-corrosive metals and alloys that will make unnecessary the annual replacement of metals estimated to cost about three hundred millions of dollars.

Similarly, the whole field of protective coatings offers an opportunity for research that has seemingly not been widely realized. The electroplaters' art is still founded to a large degree upon empirical methods and formulas, but a few men of ability have applied themselves to these questions and have developed approved methods based upon their scientific data which have demonstrated their utility. It seems strange that those concerned with paints and varnishes have failed to take into adequate consideration the differences in the various woods to be coated, for until recently practically the same procedure and the same materials have been thought applicable to all kinds of woods. The men who know woods but not paints and those who know paints but not woods are beginning to labor together, and ultimately we should know the best treatment under all circumstances to give us better and more enduring coatings in accordance with the requirements of service.

But all our losses are not due to rusting or rotting. Marine structures, for example, have for many years been the subject of attack of borers such as the Teredo, responsible for extensive damage often inflicted in a single season. What promises to be

one of the most useful peace-time contributions of the Chemical Warfare Service lies in this direction. The application to marine piling of toxic compounds discovered in the course of research pertaining to national defence has given, according to experiments extending over many months, the first real promise of coping with these destructive little mollusks that has come to us in several years.

In insecticides and fungicides, research is directed toward a more thorough application of the poisons used, as in the treatment of citrus trees under tents with hydrocyanic gas, and in the dusting of cotton with calcium arsenate, with the material in such a physical condition that a thorough covering of all parts of the plant is obtained. Another objective is to secure such adherence of poisonous dusts and sprays to the plant as to obviate the present necessity of repeated expensive applications. The secret in this appears to be the preparation of the insecticide or fungicide with an electric charge upon the particle opposite to that possessed by the green leaf. It has been done in the case of lead arsenate, the resulting material adhering to leaves under the most adverse weather conditions. Dusting with calcium arsenate by means of the airplane indicates that the particles discharged by the mechanism provided for the purpose are endowed with a positive charge, which attracts and holds them to the negatively charged leaf. Since the dusting of cotton has usually been confined to the earliest hours of the morning when the dew may cause adherence of the dust, and frequent rains sometimes render the expensive dusting useless, it is obvious that a dust that could be applied at any time, preferably by day when the thoroughness of the operation could be easily observed, and adhere to the plant regardless of the weather, would tend to increase the use of the only means which so far seems likely to decrease losses due to the weevil.

Coupled with this problem is that of forest protection against various moths and blights, which have already laid a heavy hand upon New England, Pennsylvania, and other parts of the country. The possibility of an annual dusting of large forest areas with a material that would adequately cover and adhere to all vegetation, although initially expensive, might easily prove so effective as to constitute one of the wisest investments possible.

Another important trend of our modern research is the pro-

tection, or rather preservation, of our harvested crops. Little understood fungi and plant diseases sometimes destroy 75 per cent. of the sweet potato crop between the harvest and the table. The potato scab is a destructive agency in the white or Irish potato industry, and you are familiar with the part played by the Hessian fly and rusts in determining the price of our wheat. Many other instances might be mentioned, but it seems clear that, if these annual losses are to be avoided, it will be due to the efforts of the chemist in coöperation with the agronomist, the phytopathologist, and the entomologist.

A demand once established becomes restive under restrictions. America has become the greatest silk-using nation. Her raw material is all imported. The conditions of its production are uncertain, and wide fluctuations in the price of raw silk become a nightmare to silk manufacturers, who must contract to deliver months in advance. The statistics on the production of artificial silk are most interesting and show an expansion of the trade which has made possible the sale of nearly all varieties and grades of artificial silk thus far offered. Important steps in the production of artificial silk are still empirical. The goal of artificial silk manufacturers is the production of a fibre of greater strength and the ability to spin silk sufficiently fine for the sheer fabrics now in vogue. While both these objects may be accomplished ultimately by the use of sizing and finishing materials, I am of the opinion that production will never be upon the soundest basis possible until more is known of the structure of the cellulose molecule. With this knowledge the manufacture of artificial silk could be made a science, and the demand for natural silk would decrease to the point where price fluctuations over wide ranges would be rare indeed. The difficulty of satisfactorily dyeing silks of the cellulose acetate class has limited the use of this material, which possesses certain superior characteristics; but that obstacle has been practically overcome and continued research in the field may be expected soon to remove all objections.

Another observation may be made on the trend of research in this industry. There is a possibility that with such improvements as may be expected when the cellulose molecule is understood, serious consideration must be given artificial silk as an ultimate competitor of cotton. Already the cost of materials for the production of one pound of this silk is no greater than the cost

of the raw cotton fibre. The silk is ready for weaving. The cotton must still undergo many processes before it can go into fine cloth. The spread between the two operations is therefore not great, and artificial silk has not seriously interfered with cotton thus far because it enjoys an insistent demand at a much higher price. How long cotton will continue as king may be determined in the chemical laboratory.

Nature has become somewhat uncertain in its supply of fossil gums, and we look to synthetic resin and ester gums to take their place. That this has already happened to a large extent is indicated by the satisfactory growth of these commercial enterprises. Indeed, protective coatings made from such resins and from nitrocellulose now offer the most active competition in the paint and varnish industry, and some forms threaten to supersede the older coatings within a very short time. The men engaged in this research strive to provide coatings with better anchorage, greater elasticity to withstand the changes due to temperature and moisture, to resist the abrasion of wind and dust, and to be inactive to the various cleansing agents and foreign substances with which they come in contact. It is again a case of economy and conservation.

In several industries of great importance to the public, development awaits the perfection of materials used in relatively small quantities. For example, the economic distribution of electric power depends, among other things, upon insulating materials. An increase in transmission voltage required for distribution over large areas makes it more difficult to keep the energy on the lines. It has a great tendency to leak and follows any course offered into waste channels. The electrical engineer calls to his assistance the chemist and the ceramist, who have together provided insulators which have made possible such transmission as we have, and which will ultimately be a vital factor in superpower lines. The chemist who has devoted himself to insulating materials involving gums, waxes, rubber, and the like, has contributed enormously to the transmission of power and to the perfection of communicating systems. Insulating varnishes also present a continuing problem in research, for they must satisfy the most rigid specifications, one of which is high efficiency at elevated temperatures. It is doubtful whether progress will be made in some types of elec-

trical machinery until such varnishes can be made to withstand higher temperatures than can those now available.

It is also important to carry within a single cable as many telephone wires as possible, and the success in providing special papers for insulation, alloys of greater transmission ability, and cables to withstand adverse conditions of moisture and corrosion has kept our cost of communication within its present figure.

In places where nature may become exhausted, we naturally find some of the greatest rewards for modern research, and some of our most capable scientists hard at work. We are frequently reminded of the part cracking processes have played in enabling our petroleum resources to meet the ever-increasing demands upon them. Scientists believe that what has been accomplished is but the beginning of possibilities. Too few men of ability have been employed upon the chemistry of petroleum, and until crude oil can be converted into fluids suitable for internal combustion motors to the extent of 100 per cent., this problem cannot be included under the heading of finished business. Even when that has taken place, there may still confront this group of scientists the task of converting coal and other solid fuels, by hydrogenation or other means, into the more useful liquid form.

The appalling waste characterizing our use of the forests, the extent to which we have become a paper civilization, and the apparently sudden realization that we are using our timber four times as fast as new supplies are being produced, serve to direct research in dendrochemistry toward the perfection of processes for using woods heretofore considered unsuited for pulp, and the search for new paper-making materials. You are familiar with what has been done in the preparation of cotton linters for paper stock, and some recently announced work indicates that some woods which have been believed unsuited will make a satisfactory grade of paper for the less important uses. Ways must be found for using such short-fibred pulp as can be produced from cereal straws with wood fibres, and in time we may come to be very strict in allowing certain grades of paper to be used for purposes that are obviously of temporary value. The research that can open up new sources of useful fibre will be largely rewarded.

In pointing out that research on the utilization of low-grade ores is of great value, I am not unmindful of what has been done in this direction. Succeeding generations, however, will be

required to discover large ore bodies not now known or to work deposits that we now look upon as unprofitable. The success of those concerned with the use of oxygen in metallurgical processes may contribute important information to this problem. But when we remember that in the last two generations, if indeed not in our own generation, more metal has been used than in all previous history, the emphasis to be placed upon the purpose of research in the utilization of low-grade ores will be justified.

Our increased knowledge of the chemistry of colloids has suggested the possibilities in the handling of some raw materials, such as rubber, to preserve original characteristics and insure homogeneity of quality. To learn the constituent compounds liable to decomposition and how to preserve them has resulted, in the case of rubber, in a new material, latex preserved in ammonia, applicable in many industries. Judging by the progress made when a new structural material is found or when a substance suddenly passes from a museum curiosity to an article of commerce, we may expect great things from research in such directions.

Transportation is giving rise to increasingly difficult problems. The acquisition of a cushion rubber-tired phæton was an event in the town where I lived in my college days. To-day we easily distinguish between the exhaust of the automobile and the airplane, but scarcely look up while the modern marvel in transportation flies over us. We are even promised air-taxis at twenty cents per mile in the near future, and to-day balloon fabrics are rapidly becoming as important as steel rails. We are inclined to smile at the worries of those early Englishmen who anxiously regarded the disappearance of the yew tree, because it was considered the only satisfactory source of wood for long bows and without long bows England might be defenceless. Later, other Englishmen felt certain that the requirements of the English navy would surely exhaust the oak suitable for the construction of ships' knees. Still later, another group worried because the threatened charcoal shortage might limit the production of iron for national defence. To-day, the world looks with some jealousy upon the American supply of helium. Light, strong alloys, balloon fabrics that are elastic, inert chemically, and impermeable, problems of gas purification, the condensation of moisture from the exhaust of internal combustion motors to compensate the loss

of weight with fuel consumption and so conserve gas, and a host of like questions crowd in upon those who conduct research in chemistry, physics, and the several branches of applied science which we designate as engineering. To increase safety, ease of handling, lifting power, speed, radius of operation are purposes for which such research is being conducted. Transportation in the air is a problem that really should concern us as individuals and the proper support of an air program by the Government would go a long way toward bringing commercial aviation in the very near future.

Similarly, new problems in food production are upon us. It may not occur in our day, but research in progress will doubtless make it possible, when necessary, to designate certain areas in which given crops are to be produced. Such areas can be designated when we know more of soil physics and soil chemistry, the relation of soil acidity, and particularly the true physiological salt requirements of plants. Our knowledge of fertilizers has been principally about nitrogen, phosphorus, and potassium, and we are just beginning to know how important even minute traces of other elements may be to satisfactory plant growth. Some one has discovered that among other reasons for the success of Kentucky race horses is the fact that the blue grass enables these horses to maintain a satisfactory calcium balance, and along with our problems of human nutrition we must study those of animal nutrition, so long as we use the farm animal as a converter of roughage into forms of energy which we can use. We must develop ways for feeding to animals only such foods as the human being cannot digest. *Via* hogs we utilize only 16 per cent. of the energy in corn. Satisfactory progress in the fixation of atmospheric nitrogen gives reason to believe that there will not be the once threatened nitrate starvation, as predicted by Sir William Crookes several years ago, but we know little of the nitrogen cycle and have a great deal to accomplish before we can imitate the legumes which fix nitrogen at atmospheric temperatures and pressures without any commotion. It is no lack of appreciation of what has been accomplished in this difficult field of catalysis to point out how necessary it is to learn to work at lower pressures and lower temperatures and to find still better and more economical ways for the preparation of the gases required.

That new sources for such essential foods as carbohydrates

are to be expected as a result of the present trend of research is indicated by at least two successful experiments. After many years of research a dry, granular dextrose has now been made available in commercial quantities. Recent announcements indicate that levulose produced from the inulin occurring in the mammoth French white Jerusalem artichoke and the dahlia may some day replace sucrose from the cane and beet. It is too early to predict how far this work may lead us, but experiments on a large scale indicate commercial possibilities of no mean order. No one is ready to predict that the laboratory will actually replace natural products for the production of our foods, but this must not be listed among the impossibilities. If research now in progress succeeds in showing how to build up nitrogen-bearing compounds from simple materials, or carbohydrates from carbon dioxide and water, there is always the possibility of producing such substances on a commercial basis, particularly when we remember the low efficiency with which plants are shown to utilize solar energy.

Synthesis offers the greatest possibilities, which increase in geometrical ratio as we learn more about the molecule and the atom. At the moment the synthesis of naturally occurring compounds occupies many research groups, more especially where those compounds as they occur in nature lack uniformity in quality and are found far removed from the point at which they are needed, or occur in such forms as to render separation and purification an expensive undertaking. It has been demonstrated that, following the identification and isolation of active principles, the possibilities of synthesizing the material itself are greatly increased, and the series of investigations looking to such accomplishments come first in the activities of many laboratories. It has been said that chemistry has progressed from the blackboard to a structural science, which means that carefully worked out theories are beginning to bear important fruit, and especially so in industries where synthesis is properly evaluated.

We are naturally impressed with opportunities in the field of chemicotherapy. It is not enough to prepare in dependable pure form a known concentration of active principles of naturally occurring compounds. However important this work, it is surpassed by compounds built up for a particular application and with the needs of the physician specified. Efforts to introduce

arsenic and mercury into the human body to destroy invaders without upsetting the delicately balanced mechanism of the human system have been largely successful. Such substances are molecules made to order. A special fat has been prepared for use where natural fats give objectionable products on digestion. Certain types of diseases have been overcome or restricted with the aid of compounds made in the laboratory, and there is reason to believe that a continuation of this research in synthesis offers the greatest hope to the race in its efforts for longevity, and particularly an increase in that period of life which may be described as productive. At the moment, the chemical combination of metallic salts with bacteria, coupled with an antitoxin serum treatment, permits us to hope conservatively for victory over one of the few remaining diseases that scourge the race.

The trend and purpose of modern research, therefore, is to obtain that intimate acquaintance with nature that will permit continued progress in so changing materials as to render them more serviceable to our needs as they have developed throughout the years. If we are to enjoy a longer, safer, and more satisfactory type of existence with the minimum of disease, famine, and drudgery, we must look to a wider application of science and more adequate support of the fundamental research upon which the applications of scientific principles depend. We must also impress upon the public at large the truth of Pasteur's statement:

"In our century science is the soul of the prosperity of nations and the living source of all progress. Undoubtedly the tiring daily discussions of politics seem to be our guide. Empty appearances! What really leads us forward are a few scientific discoveries and their applications."

As our defences are straightened against those elements which strive to impede our progress, limit our development, raise barriers against and destroy us, may we be able to say as did the Biblical historian, "So built we the wall."

THE THEORY OF THE SCHROTEFFEKT.*

BY

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(1) *Introduction.*—The space current in a vacuum tube is not the steady flow of a continuous fluid. It is a migration of discrete particles which possesses regularity only in a statistical sense. Either the discrete nature of the particles or the inequality in the time intervals between them would be sufficient to affect any receiving circuit that could distinguish between steady and variable currents. The magnitude of the effect might conceivably be very small, but if it were sufficiently amplified by a perfect amplifier, it could be made to actuate a telephone receiver. It would then manifest itself as *an audible noise.*

If some other fluctuation, such as an attenuated telephone message, were superposed on the original space current, it would be amplified to exactly the same degree as the statistical fluctuations and would likewise result in *an audible signal.* The intelligibility of the message thus received would then depend upon the ratio of the signal amplitude to the amplitude of the statistical variations. If this ratio were too small, the noise would mask the signal and the result would be worthless for communication purposes. In other words, even with perfect amplifiers, there is a lower limit of intensity below which electrical signals cannot be detected by vacuum tubes, because of the lumpiness of the space current in the first tube.

A number of physicists have been attracted to the problem of finding this limit from statistical arguments. Strictly speaking they have failed in the attempt, for the physical state with which they have dealt—in which the effects of space charge are negligible—does not apply to the matter of amplification at all. Amplification occurs when the space current is limited by the space charge, and it is a well-known experimental fact that there is comparatively little noise in such cases. But if the studies have failed

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to set a limit on amplification, they have aroused interest in a phase of electron emission which is important in itself, and have arrived at results which, considering the speculative nature of the subject, agree remarkably well with suitably controlled experiments.

The present paper is no more general than the others, in the sense that it contributes nothing to the subject of amplification. But it does apply to any type of measuring circuit, which the earlier studies did not, and to that extent represents a gain in generality. In addition, the hypotheses upon which the argument rests are stated explicitly and in physical terms, and the whole discussion is attached to a skeleton of physical intuition, in order that it may not be too difficult to determine how these hypotheses should be reconstructed to eliminate discrepancies between theory and experiment.

The paper consists of three parts. The first is devoted to the "frequency spectrum of the electron stream" and reaches the conclusion that no such frequency spectrum exists. The second presents a different mathematical approach to the subject and explains the physical hypotheses upon which it is based. The third contains several theorems which materially simplify the labor of computation.

Although the proposition stated in the first part is purely negative it cannot well be omitted, for the existence of such a spectrum seems so plausible at first thought that many physicists have assumed it to exist. This has even been true of some of those who have written on the Schroteffekt, and who have, in consequence, used methods of approach for which there is no adequate justification, although, fortunately, the results have been approximately correct.

(2) *The "Frequencies in the Electron Stream."*—The "noise" in a tuned measuring instrument is found to vary with the frequency to which it is tuned. It is natural to think that this fact attests the existence of an energy spectrum in the electron stream. But this is not the case. To see this, disregard any electrical connections whatever, and, to start with, consider a single electron passing through an imaginary area, A, normal to its direction of motion. As an electron transfers a certain amount of electricity it must be regarded as giving rise to a pulse of current through the area A. Whatever the nature of this pulse, it may

be represented by a Fournier integral composed of an infinity of steady sinusoidal oscillations, each with its appropriate amplitude and phase. The amplitude is an absolute property of the current pulse and can only be changed by altering the form of the pulse. The phase is purely relative and may be varied at will by moving the pulse along the time axis, that is, by changing the time at which the electron passes through the area A. For this reason the amplitude usually possesses greater physical interest than the phase. When it is plotted as a function of the frequency it is called the "spectrum" of the current. From a mathematical point of view the spectrum might more properly be regarded as a combination of both properties. It would then be a vector function, associating with each frequency a vector the length and direction of which correspond to the amplitude and phase required by the Fourier integral.

When two pulses occur, whether simultaneously or not, the combination also has a Fournier integral expansion. Moreover, this expansion may be obtained by adding together the two expansions which characterize the individual pulses. This amounts to the same thing as saying that the spectrum of the combined pulses may be obtained by adding together their separate spectra. Of course, vector spectra are meant, and the addition is therefore vector addition.

Next, consider a large number of electrons, but let their times of transit through the area A be distributed statistically at random. The spectrum vector corresponding to any frequency may be found for the group as a whole by adding together a large number of vectors, one for every electron which passes through A. Since the pulses have been assumed to occur at random times, the direction of any vector is as likely to lie within one element of angle as another. If the electrons are all identical and move with equal velocities, the lengths of the vectors must all be equal, for the current pulses are then all of the same form. But if either the electrons themselves or their velocities differ, the vector lengths are likewise unequal. In either case the sum to be expected may be inferred from a somewhat similar condition which arises in a more familiar branch of physics.

The total displacement of a particle subjected to Brownian movement, after it has experienced a number of impacts, is also equal to the sum of a number of vectors, of various directions

and lengths. But it is well known that after a sufficiently large number of impacts (that is, after "transient effects" have disappeared) the position of such a particle bears no detectable relation to its initial position. It is just as likely to be in one direction from its original position as another; and it is probably a very long way off. By analogy, there is no definite limit which the present value of the spectrum vector tends to approach as the time at which emission began recedes into the distant past, and there is, therefore, properly speaking, no "spectrum of the electron stream."

Mathematical investigation confirms these results. To give it in detail in this place would consume unnecessary space. It may be well, however, to state the result in a more exact form: *If electrons have been emitted in a statistically steady stream for infinite time past, the probability of the spectrum corresponding to this emission having any preassigned ordinate at any given frequency is zero, and the probability that the ordinate exceeds any finite quantity, however large, is unity.*

Of course, the above discussion deals with amplitudes and not energies. This, however, is of no particular consequence, for the energy spectrum is uniquely determined by the amplitude spectrum, and if one does not possess a limit, the other cannot.

(3) *The Physical Foundations for a Mathematical Approach.*—The arguments presented in the last section rule out the existence of a spectrum determined *solely* by the electron stream. However, they do not thereby deny the existence of that "noise" which the physicist measures, nor of its variation with the frequency to which the receiving device is tuned. They merely assert that it must depend in a very essential fashion upon something which has not so far been taken into account. That something is the measuring instrument itself. Not only can the relative energy content of various frequencies not be *obtained* without a measuring device; it does not even *exist* apart from it. Hence the only feasible mathematical approach must begin with the laboratory procedure.

What is done in the laboratory is this: The frequency is "isolated" by means of some sort of selective device, and then the energy dissipated in an associated measuring instrument is observed. If the device obeys the law of superposition, and if

it is subjected to a disturbance consisting of a steady (d. c.) component and a number of simple harmonic components, the amount of energy dissipated will be the sum of the several amounts which would have been dissipated had the frequencies been separately applied. This can be stated mathematically by means of the equation

$$W = W_0 + \sum_f W_f,$$

where W_0 is the energy corresponding to *average current and average electromotive force.*

The summation $\sum_f W_f$ represents the amount by which the result differs from what it would be if the flow were "steady." It can therefore properly be called the noise in the circuit. Denoting it by S (Schroteffekt), the formal relationship,

$$W = W_0 + S, \tag{1}$$

is obtained. In other words: *The Schroteffekt will be measured by the difference between the energy actually dissipated in the measuring circuit, and the energy that would be dissipated if the electron stream were a uniform flow of a continuous fluid.* Since the value of W_0 may be regarded as known, the problem reduces to the determination of W.

In order to obtain a correct result, exact knowledge of a number of properties of the physical system is required. For instance, electrons are known to be emitted in an irregular fashion. But there are many types of irregular emission and the value obtained for the Schroteffekt will depend to a considerable extent upon the type chosen. In addition, there are certain theoretical questions regarding the behavior of the measuring device which must be answered before the necessary mathematical foundation is complete.

Exact knowledge regarding these things does not exist. It is therefore necessary to lay down a set of plausible hypotheses, and hope for the best. If, after the answer has been derived, it is found not to agree with the results of experimental observation, new hypotheses must be sought which will serve the purpose better.

In this paper it is assumed:

(*a*) That the system obeys the law of superposition, so that

the aggregate current and electromotive force due to a number of electrons are the sum of their separate currents and electromotive forces;

(*b*) That the emitting and measuring systems are in "statistical equilibrium," that is, that control conditions have been maintained constant for a sufficient length of time to insure the belief that all transient effects have died out. For mathematical purposes this "sufficient length of time" must be taken infinite;

(*c*) That the electrons are emitted independently of one another, in the sense that the chance of an electron being emitted during a very small observation interval depends only upon the average rate of emission and the length of the interval, and is not altered by knowledge of recent accidental departures from the average;

(*d*) That the magnitude of the Schroteffekt is defined by equation (1). It is therefore the difference between the time average of the power dissipated in the measuring device and the power that would be dissipated if all the irregularities of the electron stream were smoothed out.

(4) *Computation of the Average Power in the Measuring Device.*—Consider a time interval T so long that the cumulative current and electromotive force due to all those electrons which were emitted before the interval T began have practically vanished by the time it ends.[1] At the end of the interval there is an instantaneous power EI in the measuring device. Its value is unknown, of course, but if a sufficient number of such intervals are observed the results of the observations will give a well-defined average which may be called $\overline{EI}$.

Among a large number, N, of such intervals there will be a certain number during which exactly n electrons are emitted. Let this number be N_n and let the average of the instantaneous

[1] It may be noted in passing that (mathematically) non-dissipative measuring devices are ruled out by this condition. Such devices are not used by the physicist, however. Even the idealized non-dissipative circuits which he deals with in theoretical studies are the limits toward which dissipative circuits approach as the dissipation is caused to vanish. Such circuits can be treated by the methods here used.

powers at the ends of these intervals be denoted by $\overline{EI}_n$. Then it follows from the definition of an average that:

$$N \cdot \overline{EI} = \sum_n N_n \cdot \overline{EI}_n,$$

or

$$\overline{EI} = \sum_n \frac{N_n}{N} \cdot \overline{EI}_n. \tag{2}$$

As N increases without limit $\frac{N_n}{N}$ becomes *the probability that an interval, chosen at random, belongs to class n;* while $\overline{EI}$ and $\overline{EI}_n$ approach the true theoretical averages corresponding to an infinity of trials. Hence (2) becomes

$$\overline{EI} = \sum_n p(n)\, \overline{EI}_n. \tag{3}$$

In other words, $\overline{EI}$ can be found by finding the probability of exactly n electrons in a time T, together with the average power at the ends of many such intervals.

Assumption (c) permits $p(n)$ to be written down at once. Its value is

$$p(n) = \frac{e^{-\nu T}(\nu T)^n}{\underline{|n}}, \tag{4}$$

where ν is the average time-rate of emission.[2]

The computation of $\overline{EI}_n$ requires a little more labor. It may be effected by regarding the set of n electrons as having been made up by superposing two subsets of $n-1$ and 1, respectively. By

[2] By (c) the chance of an electron being emitted in time dt must be νdt, if dt is so small that its higher powers may be ignored. Otherwise the average rate of emission would not be ν. In T there are T/dt such intervals, all of which are independent in the sense that whether an electron was or was not emitted during a particular interval plays no part in determining the probability that one was emitted during any other interval. Hence, the chance of n electrons in T is

$$p(n) = C_n^{T/dt}(\nu dt)^n (1-\nu dt)^{n-T/dt}$$

$$= \frac{(\nu T)^n \left[(1)\left(1-\frac{dt}{T}\right)\left(1-\frac{2dt}{T}\right)\cdots\left(1-\frac{(n-1)\,dt}{T}\right)\right]\left[(1-\nu dt)^{-\nu T/\nu dt}\right]}{\underline{|n}\,(1-\nu dt)^{-n}}.$$

This formula holds provided "dt is small enough," which can only be assured by letting it vanish. But when dt approaches zero the first bracketed factor approaches unity, the second approaches $e^{-\nu T}$, and the denominator approaches $\underline{|n}$. The entire expression therefore takes the form (4).

virtue of assumption (*c*) this can be done in such a way that both subsets satisfy all the hypotheses of the problem.[3] The electromotive forces and currents due to these sets may be denoted by E_1, I_1, and E_2, I_2, respectively, and their random probabilities by $P_{n-1}(E_1, I_1)$ and $P_1(E_2, I_2)$. As the instantaneous power is $(E_1 + E_2)(I_1 + I_2)$, it follows at once that the average power $\overline{EI}_n$ is given by the formula

$$\overline{EI}_n = \int dE_1 \int dE_2 \int dI_1 \int dI_2 [E_1 I_1 + E_2 I_1 + E_1 I_2 + E_2 I_2] P_{n-1}(E_1, I_1) P_1(E_2, I_2),$$

the limits of integration being, in every case, from $-\infty$ to $+\infty$. Inspecting the four terms of this integral separately, it is found that each of them reduces either to an average or to a pair of averages, the entire expression taking the form

$$\overline{EI}_n = \overline{EI}_{n-1} + \overline{E}_1 \overline{I}_{n-1} + \overline{E}_{n-1} \overline{I}_1 + \overline{EI}_1. \tag{5}$$

By virtue of assumption (*a*) it follows at once that

$$\overline{I}_{n-1} = (n-1)\,\overline{I}_1$$

and

$$\overline{E}_{n-1} = (n-1)\,\overline{E}_1.$$

If these values are substituted in (5), the general law

$$\overline{EI}_n = \overline{EI}_1 + n(n-1)\,\overline{E}_1 \overline{I}_1 \tag{6}$$

may be obtained by mathematical induction.

The evaluation of $\overline{EI}$ is now possible. Substituting (4) and (6) in (3), and noting that

$$\sum_{n=0}^{\infty} np(n) = \nu T,$$

$$\sum_{n=0}^{\infty} n(n-1)\,p(n) = (\nu T)^2,$$

it is found that

$$\overline{EI} = (\nu T)\,\overline{EI}_1 + (\nu T)^2 \overline{E}_1 \overline{I}_1. \tag{7}$$

[3] Suppose the n electrons came from the interior of a circle drawn about a point P on the emitting surface. An area can be marked off about P such that within this area one and only one electron appeared during the interval T. By virtue of assumption (*c*) the two areas function independently of one another, one giving a subset of $n-1$, the other a subset of 1.

The few remaining steps of the argument are easily interpreted in terms of this picture.

This equation can be simplified further by the following considerations:

Strictly speaking $\overline{E}_1$ is the average over a large number of intervals T of the electromotive force at the end of the interval, it being understood that one electron and only one was emitted during the interval, and that the interval is so long that the contributions of electrons emitted during the epoch which precedes it is negligible. Due to the second condition, only the end point of the interval is of importance. Hence the same average would be obtained by making random observations on the effects of single electrons, subject only to the condition that no observation may be made more than T seconds after the emission of the electron in question. By definition, however, this process gives the average value of E during the first T seconds after emission. A similar argument applies to $\overline{I}_1$, $\overline{EI}_1$ and $\overline{EI}$.

With this interpretation in mind $\overline{EI}$ is seen to be identical with the symbol W of equation (1).

Furthermore, it follows at once from assumption (a) that $\nu T\overline{E}_1$ is the time average over the interval T of the electromotive force due to νT electrons. As T becomes infinite, this latter time average becomes identical with the average electromotive force in the measuring device under conditions of statistical equilibrium. In other words, $\nu T\overline{E}_1$ approaches $\overline{E}$. Similarly $\nu T\overline{I}_1$ approaches $\overline{I}$. The last term of (7) therefore reduces to $\overline{E}\cdot\overline{I}$, which is identical with the W_0 used in equation (1).

In the one remaining term of (7) the product $T\overline{EI}_1$ represents the total energy dissipated during the first T seconds after emission of an electron, if only this one electron is allowed to be emitted. As T becomes infinite, this approaches the average over all electrons of the energy that would be associated with each one of them separately if no other had ever been emitted. This may be called $\overline{w}_1$. Substituting these symbols in (7), it takes the form:

$$W = \nu\overline{w}_1 + W_0 . \tag{8}$$

Comparing this with (1), the final result,

$$S = \nu\overline{w}_1, \tag{9}$$

is obtained.

(5) *The Evaluation of the Mean Energy* $\overline{w}_1$.—The above argument is satisfactory from the logical standpoint, but the

result is expressed in terms of a physical quantity, the magnitude of which is unknown. This quantity $\overline{w}_1$ represents the energy which would be expected to be dissipated in the measuring device if one electron and only one were ever emitted. It can best be understood in terms of the physical picture presented in footnote 3. If the hot cathode is divided into a very great number of very small elementary areas in such a way that throughout all time one and only one electron is emitted from each of these elementary areas, and if each of the areas is then assigned to its own anode and measuring device independently of all the rest, each of these measuring devices will receive for all time one and only one surge of current. Each of them will dissipate an amount of energy w_1, but the amount need not be the same for all circuits. If not, the average of $\overline{w}_1$ over all the various circuits is the $\overline{w}_1$ which enters into equation (9).

I know of no reliable method of finding this quantity—statistical average though it is—either in the laboratory or in the computing room, and yet without some method for obtaining it the theory developed above amounts to little more than a mathematical exercise. It is therefore imperative that some sort of additional hypothesis be introduced, even though that hypothesis be not capable of adequate justification. The hypothesis adopted in the remaining sections of the paper is suggested by the following line of argument:

The filament and plate of the tube form a condenser. When an electron passes from the one to the other, it upsets the statistical equilibrium existing among the free electrons of both, so that a redistribution of these electrons becomes necessary. During this redistribution a "steady drift" is superposed on the chaotic thermal motion of the electrons, and a "steady field" is superposed on the chaotic fields within the material. The thermal motion in the presence of the chaotic fields is conservative and causes no dissipation of energy in the measuring device. It is only when a "steady drift" and "steady field" exist that energy dissipation takes place.

When the condenser is charged with a very large number of electrons, the steady drift becomes an ordinary current and the steady field becomes a potential drop of the sort dealt with in ordinary circuit theory. Under such conditions the energy dissipated during the discharge of the condenser can easily be found.

But this is a statistical effect, and it is a violent assumption to say that a *single* electron *on the average* sets up currents and dissipates energy in this way. That assumption, however, is here made in order that the study may proceed. As a result, the problem degenerates into a consideration of the discharge of a condenser through the measuring circuit, as viewed in ordinary circuit theory.

Let ε represent the electronic charge, and let $e(t)$ and $i(t)$ be the current and voltage in the measuring device due to *unit* charge placed on the condenser at the time $t = 0$. Then in accordance with our hypothesis:

$$\bar{w}_1 = \varepsilon^2 \int_0^\infty e(t)\, i(t)\, dt.$$

When this is substituted in (9) and it is noted that the product $\nu\varepsilon$ is equal to the space current i_0, this equation takes the form

$$S = \varepsilon i_0 \int_0^\infty e(t)\, i(t)\, dt. \tag{10}$$

For purposes of computation this formula can be still further simplified by means of a rather remarkable theorem originally suggested by Mr. J. R. Carson and generalized by Mr. L. A. MacColl. In obtaining this theorem, an electromotive force is supposed to be applied in the initial branch of a network, and to lead to an electromotive force $E(t)$ and a current $I(t)$ in the terminal branch. It is supposed, moreover, that the impedance of the terminal branch (across which the electromotive force $E(t)$ is measured) is $z(\omega)$ and that the transfer impedance from the initial to the terminal branches is $Z(\omega)$. Finally, the (complex) amplitude function in the Fourier integral expansion of the applied electromotive force is denoted by $\psi(\omega)$. Then the Carson-MacColl theorem states that [4]

$$\int_{-\infty}^{\infty} E(t)\, I(t)\, dt = 2\pi \int_{-\infty}^{\infty} z(\omega)\, \frac{\psi(\omega)\ \psi(-\omega)}{Z(\omega)\ Z(-\omega)}\, d\omega. \tag{11}$$

[4] It is not difficult to establish this theorem by means of plausible formal transformations, and a rigorous proof can be built up if the integrand on the right-hand side of the equation vanishes to a higher order than the first as ω becomes infinite. This condition, however, has not been shown to be necessary as well as sufficient, so that the exact range over which the theorem is valid still remains unknown. Fortunately the example which follows is one to which the existing proof applies, so that there can be no question as to the accuracy of the result.

In the case of the Schroteffekt it is not the electromotive force in the initial branch which is known as a function of the time. What is known is the charge placed on the condenser formed by the filament and plate, which charge thereafter dissipates itself in the usual fashion. The Carson-MacColl theorem therefore fails to cover the case of the Schroteffekt directly; but by means of a suitable artifice it may still be made to apply.

Consider the circuit shown in Fig. 1, in which the condenser C is ultimately to be regarded as the tube, of which Z_0 is the output impedance, while E and R are fictitious elements. It is assumed that R is so large as to mask the other impedances. Ultimately it will be made infinite. Similarly E is supposed to be a pulse of the same form as that which represents the rate at which the condenser C is charged when an electron passes from filament to plate,[5] but the magnitude of E is taken large enough to drive *unit* charge through the resistance R. It is obvious that such an electromotive force will produce the same disturbance in the measuring device as would the transfer of unit charge between filament and plate; in other words, it will lead to exactly that

[5] Perhaps this idea needs a little elaboration. The process of transferring an electron from cathode to anode requires a finite time. Hence the charge in the condenser is not acquired suddenly, but gradually, due to a sort of "electrical image" effect. The rate at which the charge is acquired is therefore a function of the time, which may be denoted by $\varepsilon f(t)$, the exact form of expression being so chosen that $f(t)$ corresponds to the transfer of *unit* charge. The idea intended to be conveyed by the text is then simply this: The electromotive force E is chosen as $Rf(t)$, in order that the condenser C may acquire *unit* charge at the rate $f(t)$; just as it would acquire an *electronic* charge at the rate $\varepsilon f(t)$ if an electron were transferred.

Practically, of course, the times of transit are so exceedingly short that the charge may be regarded as acquired in zero time. Then $f(t)$ degenerates into a "pure pulse of content unity," the Fourier representation of which calls for the addition of all possible frequencies, each with the same amplitude $\frac{1}{2\pi}$. In the example which follows, $f(t)$ is supposed to be of this form.

One more remark should be made. There is no reason to suppose that $f(t)$ is the same for *all* electrons. If not, a strict adherence to form would require that the above process be carried out for each electron, and the proper average formed. This is true, not only of the present argument, but of equation (10) as well, in which $e(t)$ and $i(t)$ may take different forms if determined from different electrons. These generalizations are obvious, however, and have been omitted in the interests of simplicity; especially since, if $f(t)$ is idealized to the extent of regarding it as a pure pulse, both it and $e(t)$ and $i(t)$ as well must be the same for all electrons, and averages are not required.

current and electromotive force which have been denoted by the symbols $i(t)$ and $e(t)$.

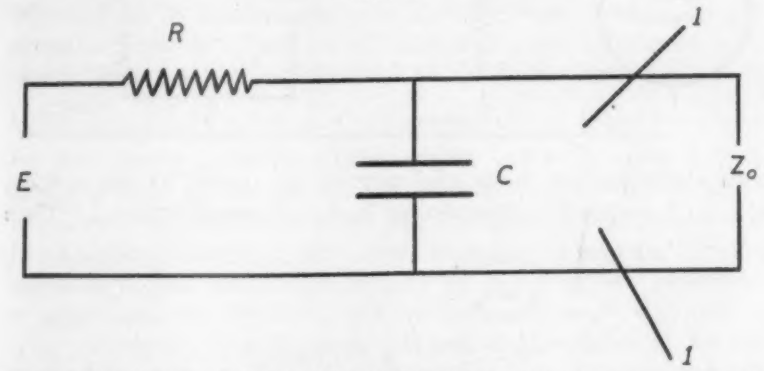
Next, suppose that when the circuit is opened at the points 1,1 and an electromotive force is there applied, the transfer impedance to the measuring device is Z. In terms of these symbols it is a simple matter to show that the transfer admittance from the fictitious electromotive force E to the measuring device is

$$\frac{Z_0}{Z}\,\frac{1}{RZ_0\,Ci\omega + R + Z_0}.$$

Hence (11) becomes [6]

$$\int_0^\infty e(t)\,i(t)\,dt = 2\pi \int_{-\infty}^{\infty} z\,\frac{Z_0\bar{Z}_0}{Z\bar{Z}}\,\frac{R^2\psi\bar{\psi}}{(R+Z_0+RZ_0Ci\omega)\,(R+\bar{Z}_0-R\bar{Z}_0\,Ci\omega)}\,d\omega,$$

FIG. 1.



where the dashes indicate the substitution of $-\omega$ for $+\omega$. In the limit as R becomes infinite, this reduces to

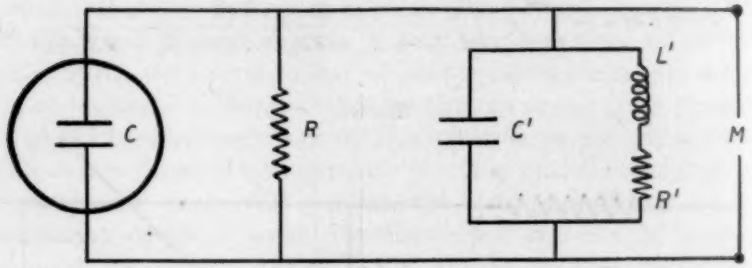
$$\int_0^\infty e(t)\,i(t)\,dt = 2\pi \int_{-\infty}^{\infty} z\,\frac{Z_0\bar{Z}_0}{Z\bar{Z}}\,\frac{\psi\bar{\psi}}{(1+Z_0Ci\omega)\,(1-\bar{Z}_0\,Ci\omega)}\,d\omega. \qquad (12)$$

The advantage of formula (12) over (10) from the standpoint of computation is obvious. In order to apply (10) it is first necessary to compute the current $i(t)$ and the electromotive force $e(t)$, which is frequently a problem of considerable magnitude in itself. On the other hand, in order to apply (12), it is only necesary to know the impedance of the circuit and the amplitude function $\psi(\omega)$ in the Fourier integral expansion of $f(t)$.

[6] Evidently $e(t)$ and $i(t)$ are zero for $t < 0$. Hence the lower limit of integration is 0 instead of $-\infty$.

(6) *Example.*—The circuit shown in Fig. 2 may serve as an illustration of the application of this method. Here C is the emitting tube, $C'L'R'$ is the tuning circuit, R is an auxiliary resistance, and M is an amplifier leading ultimately to the measuring device. This amplifier is assumed to give perfect reproduction of the voltage across the condenser C', and its impedance is assumed to be so great as to have a negligible effect upon the rest of the network. The ultimate measuring device is assumed to be a unit resistance, in which case $z = 1$. Under these conditions,

FIG. 2.



both electromotive force and current are equal to the voltage across C', except for the constant factor of amplification μ. Then

$$Z = 1/\mu,$$

$$z = 1,$$

$$\frac{1}{Z_0} = C'i\omega + \frac{1}{R} + \frac{1}{R' + L'i\omega}.$$

Also, if the charge is supposed to be conveyed to the condenser instantaneously, $\psi(\omega) = \frac{1}{2\pi}$. Substituting these values in (12) and adopting the notation $C + C' = \kappa$ and $R + R' = \rho$, it becomes

$$\int_0^\infty eidt = \frac{\mu}{2\pi L'^2\kappa^2}\int_{-\infty}^{\infty} \frac{(R' + L'i\omega)(R' - L'i\omega)\,d\omega}{\left[\omega^2 - \left(\frac{1}{R\kappa} + \frac{R'}{L}\right)i\omega - \frac{\rho}{LR\kappa}\right]\left[\omega^2 + \left(\frac{1}{R\kappa} + \frac{R'}{L}\right)i\omega - \frac{\rho}{LR\kappa}\right]}.$$

The integrand in this expression vanishes to the second order at infinity. It is therefore possible to replace the path of integration along the real axis by a circuit enclosing all the poles of the integrand in the upper half of the plane, thereby reducing the labor of integration to the simple algebraic manipulation acquired

in obtaining the residues at these poles. When this has been done, and the results are substituted in (10), it is found that

$$S = \mu^2 \frac{\mathfrak{E} i_o}{2} \frac{R}{\kappa} \frac{L' + RR'\kappa \frac{R'}{\rho}}{L' + RR'\kappa}. \tag{13}$$

If R becomes infinite, so that the shunt resistance of Fig. 2 disappears, this reduces to

$$S = \mu^2 \mathfrak{E} i_o \frac{L'}{2R'^2\kappa^2} \left[1 + \frac{R'^2\kappa}{L'}\right], \tag{14}$$

which is identical with the result obtained by Schottky,[7] Ornstein and Burger,[8] and Fürth,[9] except for the factor $\left[1 + \frac{R'^2\kappa}{L'}\right]$, which was not included in their results.

(7) *Conclusion.*—The three theoretical studies of the Schroteffekt to which reference has just been made have two points in common: They are all limited to a special type of tuned circuit; and for that circuit they all reach the same final result which agrees with equation (14) except for the factor $1 + \frac{R'^2\kappa}{L'}$. As this factor generally differs from unity by only a small amount, their results are usually sufficiently accurate to satisfy laboratory requirements. But the methods of derivation consisted either of analogy with other branches of science (Fürth), plausible formal operations difficult of justification (Schottky), or approximation methods with no evaluations of the limit of error (Ornstein and Burger). Hence it is difficult to be sure just what mathematical restrictions are actually imposed, and what they signify physically. It was the original aim of the study here presented[10] to remove this uncertainty regarding hypotheses. To accomplish this aim it was necessary to use only rigorous mathematical processes, for if plausible formal operations were resorted to, the question of the physical significance of the conditions under which they were justifiable would still remain open. By a fortunate accident this limitation as to methods

[7] "Über spontane Stromschwankungen in verschiedenen Elektrizitätsleitern," *Ann. der Phys.*, **57**, 541–567, 1918.

[8] "Zur Theorie des Schroteffektes," *Ann. der Phys.*, **70**, 622–624, 1923.

[9] "Die Bestimmung der Elektronenladung aus dem Schroteffekt an Glükathodenröhren," *Physik. Zeits.*, **23**, 354–362, 1922.

[10] The original notes from which this paper was prepared are dated February 21, 1922.

did not restrict the generality of the end result, but actually increased it. Hence, it comes about that equation (10) is more general than those previous published.[11]

On the other hand, when numerical results were desired, it was found necessary to introduce the assumption that, on the average, a condenser charged with a single electron obeys ordinary circuit equations. This condition was also used by Fürth, who openly defends it, and either it or something akin to it is implied in the work of the others. In spite of Fürth's defence, however, I feel that the necessity for this assumption constitutes the weakest point in the argument; especially since it is not the results themselves, but the getting of them, that requires its use.

Aside from this unfortunate tribute to expediency, the principal physical assumption upon which the final result is based is that the electrons are *independently* emitted. This is a very far-reaching assumption, and one which may very well not be true. It may, therefore, be wise to mention some of the types of violation which might occur, and the ways in which they would manifest themselves.

First, there might be *regularity of emission,* such as was postulated to explain peaks in Hartmann's experimental curves.[12] If the electrons came out regularly at equal intervals, the driving force to which the measuring device was subjected would be periodic. Hence, whenever the circuit was tuned to one of the harmonics of this period, it would experience too large a reaction to conform with the theory here given; while for other frequencies the reaction would be too small. Partial regularity should lead to a similar, though probably less pronounced, effect.

In the second place, dependence due to carriers of multiple charge would upset the results. For instance, if each carrier had on it *two* electronic charges, there being in consequence only half as many carriers, it is obvious from (10) that S would be twice as large. If *occasional* carriers possessed more than one charge,

[11] It is, in fact, more general than the problem of the Schroteffekt, and applies equally well to the absorption of energy by any sort of circuit from any sort of disturbance, provided the latter is "random" in character. For instance, it applies to the reception of "static" by a tuned radio receiving set, provided the individual pulses are distributed at random in time. They need not be of equal energy content nor of similar form.

[12] "Über die Bestimmung des elektrischen Elementarquantums aus dem Schroteffekt," *Ann. der Phys.*, **65**, 51–78, 1921.

the same general effect might occur: S being dependent on the circuit constants in the way given by the theory to within a constant factor greater than unity.

In the third place, if the emission of an electron always so upset the equilibrium in its immediate vicinity as to cause another electron to be emitted very shortly thereafter—the opposite of Hartmann's postulated cooling effect—the result would be very similar to that due to multiple carriers, except at exceedingly high frequencies. Again the occasional occurrence of such a phenomenon would lead to a similar, but less pronounced, effect.

Finally, due to the simultaneous action of such causes, departures from (10) might be obtained which combined in some degree the characteristics of all the various types.

Second in importance only to this requirement of independence is the requirement as to statistical equilibrium. If, for instance, the temperature of the filament were varied periodically, its period of variation would certainly appear in the final results; and if it fluctuated because of some sort of instability, a similar effect would be observed.

One of the two sets of experimental results which have been published (Hartmann's) has already been referred to. It showed peaks of just the sort to which regularity of emission might lead. Fürth suggests that they may be due to the response characteristics of the telephone used by Hartmann as a measuring instrument; and this is probably the correct explanation, for they do not appear in the (unpublished) results of J. B. Johnson. The other paper by Hull and Williams,[13] has as yet appeared in abstract only, but the results are said to confirm Schottky's theory fully. In fact, these writers say "it appears possible that this method of measuring 'e' may yield values comparable in accuracy with the oil drop method."

So far as the published experiments go, therefore, there seems to be a fair agreement with the theory, but this agreement does not exist in the lower frequency range, as is shown by Johnson's studies, which I have been permitted to see. At such frequencies his values of ε are all too large, suggesting the need of some sort of extension to the theory.

[13] "Determination of 'e' from Measurement of the Schrott-Effect," *Science*, 60, 100, 1924.

To reach complete agreement between theory and experiment may be a matter of some difficulty, but it is not without its physical interest. It is true that even complete agreement would not confirm the value of ε so long as the hypotheses were themselves less certain than the electronic charge; but it would confirm the hypotheses, thereby contributing something to our knowledge of the mechanism of electron emission.

On the Origin and Nature of the Long-range Particles Observed with Sources of Radium C. SIR ERNEST RUTHERFORD and J. CHADWICK. (*Phil. Mag.*, Sept., 1924.)—It has been known for some years that, when α-rays from radium C pass through nitrogen and oxygen, there are present certain swift particles that have a range of 9 cm. in air. These had what the authors designate a "chequered history," being first attributed to the source and later to the substance bombarded. In this paper an attempt is made to locate finally their origin.

Counts were made by scintillations on a zinc sulphide screen of the numbers of these long-range particles. Two kinds were established, having respective ranges of 9.3 and 11.2 cm. No evidence was discovered of another group of still longer range, the existence of which had been claimed by other investigators. The number of these two classes of particles that appear when α-rays from radium C are incident on helium, oxygen, xenon, carbon dioxide, silica and mica is not dependent on the substance bombarded. "The number of the 9.3 cm. particles emitted per second by a source of 1 mg. radium C is about 1050, the number of the 11.2 cm. particles about 180." It was further found that "the number and ranges of the long-ranged particles are independent of the method of preparation of the active deposit or of the material on which it is obtained." A direct proof that the particles under investigation come from radium C was obtained when a screen opaque to emitted particles was interposed between the source, radium C, and the screen on which the scintillations were observed. A definite shadow was marked out that was geometrically identical with the shadow that would have appeared had a source of light replaced the source of particles. With the additional experimental result that the usual number of 9.3 particles appears even when the source is in a vacuum, the case for attributing these to radium C may be regarded as complete. For the 11.2 particles the evidence, though not so cogent, points to the same origin. By means of the deflection of the particles in a magnetic field, those of 9.3 range were fixed as being α-particles, and the same nature is with little doubt to be ascribed to the 11.2 cm. set. "These two groups of particles probably represent new types of disintegration of radium C." G. F. S.

THE GUIDING WIRE IN ELECTROMAGNETIC TRANSMISSION.*

BY

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THE fact that energy in the form of electromagnetic waves may be transmitted at high speed through space and guided by conducting wires is a fundamentally important matter in practically all electrical systems—in electrical railroads, electrical lighting and power, telephone, telegraph and even radio broadcasting. This paper undertakes to give a brief picture of the process of electromagnetic transmission, but avoids any mathematical or quantitative discussion of the subject.

In order to give the picture we have in mind, it will be necessary to spend a considerable part of the available time recalling to your minds those most amazing ideas as to the make-up of the physical world which the physicists have given us in the electron theory. It is on these ideas that I wish to superimpose some ideas as to the nature of electromagnetic transmission and the part played in it by guiding wires.

Let us first recall the following:

(1) The world appears to be built of two types of minute elementary particles, which may be called negative and positive electrons. Each electron carries a quantity of negative or positive electricity of definite amount.

(2) Each atom of matter is made up of a combination of positive and negative electrons, having such relation to each other that each atom may be visualized as something very much like a minute solar system, the electrons being extremely minute as compared with the distances which separate them in this system.

(3) Physical bodies are made up of a group of these atoms. For example, a solid body, such as a length of copper wire, is a grouping of atoms held together presumably by the interaction between the outer electrons of each atom and thus forming a structure tending to resist deformation.

(4) Each normal atom contains an equal number of positive and negative electrons. For this reason, and because of the way

* Presented at a meeting held Thursday, February 7, 1924.

the atoms are arranged in bodies, matter does not usually exhibit what we call electrical effects, because the positive electrons neutralize the effect of the negative electrons (unless we attempt to explain gravitation as a residual electrical effect, which has not apparently been done with any important degree of success).

What are ordinarily known as electrical effects, then, are due to conditions in which electrons, more usually negative electrons, are to a more or less degree disassociated from electrons of opposite sign. The most important condition under which this occurs is in metallic conducting bodies, where a portion of the negative electrons appear to be not bound tightly into the atoms of the conducting material, but free to move from atom to atom in any direction throughout the wire, but not free to pass out of the wire at ordinary temperatures except under very great difficulty.

It is this condition of partially free electrons in conducting bodies that is of particular interest in connection with the use of guiding wires. It is interesting, however, to recall some of the other conditions under which we find partially free electrons. First, we find electrons which are actually free in space, for example, in thermionic tubes used in radio detectors and amplifiers where the filament becomes so heated that negative electrons are projected out of it. Again in liquids and in gases we find atoms or combinations of atoms containing one or more extra electrons in addition to the number necessary for normal conditions. In such cases these unneutralized electrons have a degree of freedom in the fact that the atoms of which they form a part are free to move.

In dielectric and in magnetic material we have another type of freedom of electrons, in that while they are not able presumably to escape from their atoms, there is a certain degree of mobility somewhere in the structure of the material and the effects of the electrons in the different atoms may be coördinated, and we get so-called dielectric and magnetic effects.

The second well-known conception which must form a part of this picture we are attempting to draw is the conception of electrical fields set up by electrons and which can act on other electrons.

As already pointed out, the space separating the electrons in an atom, similar to the space separating the planets and the sun in our solar system, is very large compared with the size of the

electrons or the bodies making up these systems. We cannot think of this space, however, as empty space. There is a lot going on in this space. In fact, we can perhaps be permitted to say that a large part of the " mechanism " of the universe is in this space between bodies.

To indicate what is meant, we may look first at our physical world from the energy standpoint. Energy seems to the physicist and engineer, perhaps, as one of the most tangible things with which we are concerned, perhaps more tangible than matter itself. From this standpoint we find that while the electrons are minute spaces in which energy is present with extreme density, there is energy, however, present through all the space which separates them. Energy, constantly being given out by atoms or associations of atoms, spreads through intervening space and is partially absorbed by other atoms or associations. As a matter of interest, it is estimated that the amount of power travelling through space from the sun is so great that at the distance of the earth from the sun the flow is a kilowatt and a half per square metre of cross-section.

The idea of direct action between two electrons or between larger bodies at a distance from each other with no intervening transmission of something from one to the other is one which it has never been easy to accept, and would be particularly difficult when modern theories are generally agreed that there is a lapse of time between any change in one body and the effect of that change on any other body. It seems only reasonable to assume that every interaction between bodies, including gravitation, is the result of some " mechanism " present in space. We can, perhaps, be permitted to use this term whether we conceive that the action is the transmission of waves in a medium, or the transmission of pulses of energy between bodies, or in whatever form we try to conceive it.

Our picture of the physical world, then, must not only be built up of positive and negative electrons, but also in terms of what are generally called " fields " in all of the spaces outside of the minute electrons. The conception of a field appears quite as important as the conception of the electron. In fact, in some ways we can say that the field is better known than the electron itself and that the fields are often meant when we speak of electrons. For example, we speak of an electron colliding with an atom.

What we undoubtedly mean is that they get so close together that their fields have a comparatively violent interaction on each other. We might even imagine that the electron itself is only a figure of speech, that it is, perhaps, a focal point of a particular form of field, the point at which the field becomes of maximum intensity.

Assuming, then, that the field has as definite and important an existence as the electron, how should it be conceived? The most common and useful conception of a field is as a condition of some sort in space determining the interaction between electrons, that is, a source of influence surrounding each electron which acts on every other electron, acting, of course, in general most forcibly on those which are closest to the electron causing the field.

From this standpoint, we are primarily interested, then, first, if we have an electron or a certain configuration of electrons, what field will they set up, and second, what will be the effect of such a field on other electrons?

In this paper we will steer very wide of any attempt to discuss the fields set up around the electrons, and the action of these on each other for the spaces within the atom itself. Here we have matters, regarding which the physicists disagree among themselves, which are a long way beyond the scope of this present paper, and which only an author thoroughly in touch with all present-day work along these lines could venture to discuss. For the purposes of this paper, however, in which we are interested in such electromagnetic fields as are set up in the space outside of matter, such fields as we ordinarily call electromagnetic fields, we can assume, and know that we are not making any important error, that the fields set up by electrons are just such fields as would exist in accordance with what is often called the "classical" theory, that is, the theory of Maxwell as further developed by Lorenz.

As we are interested in the action of electromagnetic fields on electrons, we can most naturally define any field in space in terms of its action on a single electron which we will assume is placed in the field. It is further assumed in doing this that the electrons causing the field are so held that the interaction of this one new electron does not appreciably affect them. Without going into detail, but to reinforce the picture we are trying to form, it will

be interesting to recall the following facts regarding electromagnetc fields:

(1) The electromagnetic field is made up of two types of fields, or perhaps two manifestations of a single field.

(2) One of these, called the electric field, causes a force on the electron independent of its motion. The electric field is very naturally described, therefore, by saying that its direction is along the line of the force acting on the electron at any point in it, and that its intensity is proportionate to this force.

(3) The magnetic field causes no force on the electron, unless the electron is in motion. We could undoubtedly describe the field in terms of any desired form of motion of the electron. The most convenient form of motion, however, is to imagine the electron spinning around an axis, but free to move so as to change the plane in which it is spinning. Assuming this motion is imparted to the electron, the axis will then take up a definite direction, and the magnetic field is described by saying that the direction of the field is in the direction of the axis of the spinning electron, and its intensity is proportional to the force required to give the axis a definite departure from this direction for any given velocity of motion of the electron.

(4) The density of the energy in each of the two fields is proportional to the square of the intensity of the field at any point.

(5) The flow of energy at any given point in a field is proportional to the product of the intensities of the two fields multiplied by the sine of the angle between them, and the direction of flow of energy is at right angles to both the direction of the magnetic field and the direction of the electric field.

So much, then, for the action of a field on an electron. Next the question as to what field is established by any particular configuration of electrons. Here we find that the intensity of a field at any given point is merely a summation of the fields of all the electrons whose effect is appreciable at that point, taking, of course, due account of the directions of the component fields, that is, the vector sum. This does not mean, of course, that the energy at a point is the sum of the energies which would be there if each of the electrons was acting by itself, as it has already been noted that the energy is proportional to the square of the intensity of the field. That is, to bring together a group of electrons into any particular configuration involves, in general,

doing work on the system of electrons, and this is necessarily reflected in the energy in the fields. It is the intensities, however, which add together directly, so that if we know completely the field surrounding an individual electron, we can determine the field of any configuration of them. It is not important for this paper to recall just what the fields are surrounding electrons. Again, as a matter of interest, however, and to reinforce our picture of the fields, we can have in mind the following brief statements: Again we should understand that these statements may be an approximation, and apparently do not at all account for the actions which take place when electrons are comparatively close together, as in atomic structures. They are, however, at all events sufficiently good approximations for the purposes of a discussion of ordinary electromagnetic action. In accordance, then, with the "classical" theory, the fields surrounding an electron are as follows:

(1) For a stationary electron the electric field can be pictured by lines spreading outward from the electron, by which we mean that the force on an exploring electron would be radially directed. The intensity of the force falls off as the square of the distance from the electron forming the field.

(2) If the electron is moving at some definite velocity, then the electric field, instead of being uniform in all directions from the electron, becomes strongest in a plane at right angles to the direction in which the electron is moving, becomes weakest along the line of motion, and has intermediate values at all points intermediate between these two.

(3) If the electron is supposed to be moving at the speed of light, then it is supposed to have its electric field all limited to that plane through the electron which is at right angles to the direction of motion. In this plane the electric field spreads out radially from the electron.

(4) For the stationary electron there is no magnetic field whatever.

(5) For the moving electron, the magnetic field is in the form of circles centred on the line of motion of the electron.

(6) At the velocity of light the magnetic field is confined to the same plane as the electric field and may be represented by circles surrounding the electron.

(7) The total field formed by any configuration of electrons is the sum of all the fields which the individual electrons would form if taken separately.

With this general picture of electrons and their fields, we have the stage set, perhaps, for a consideration of electromagnetic transmission.

Consider first a radio system, which is the simplest case of transmission. Assume further as a simple case that a vertical wire is the transmitting antenna, and that this is supplied with energy at radio-frequencies by means of a mechanical generator which is connected and disconnected from the antenna at intervals corresponding to a telegraphic code. At the receiving end, assume a vertical wire as a receiving antenna, a crystal detector in this circuit, and some proper indicating device connected across the crystal.

From the discussion we have had, we will of course picture all these physical things as made up of groupings of electrons, each atom being perhaps, as pointed out, a minute system of electrons somewhat comparable in configuration with our solar system.

The particular thing that interests us from the transmission standpoint, however, is that in the metal parts of these circuits a portion of the electrons are free to move within the metals. At the transmitting end, the electrons are set in motion by the action of the generator in which you will note that metallic conductors are either dragged through magnetic fields, or else the magnetic fields in the vicinity of the conductors are rapidly changed by proper motion of magnetical material. It is the effect of the relatively moving field that sets the electrons in motion. This, it will be further noted, involves a transformation of mechanical energy into electrical form, which is often the first step in electrical transmission.

When the generator is connected to the antenna the electrons, because of this motion of the conductors through the magnetic fields, are caused to move first in one direction and then in the opposite. At one instant there is an excess of negative electrons in the upper part of the transmitting antenna. A short time later the condition changes to the other extreme, in which there is a deficit of negative electrons at the top. The motion of the electrons

back and forth in the antenna constitutes what we know as an electric current.

From the previous discussion it is evident that the motion of these electrons must cause a change in the fields surrounding the antenna. As the fields of the electrons stretch out indefinitely, the resultant changes in fields caused by the electron motion will also extend out indefinitely. It is difficult, without a quantitative discussion, to picture just what is going on. Evidently, however, since there must be some change in field at whatever distance we go from the transmitting antenna, there will be some change in the fields surrounding the receiving antennæ, which will be appreciable if the distance from the transmitting antenna is not too great. These changes in fields will, of course, react on the free electrons in the conductors of the receiving antenna, and cause some motion in the electrons in the conductor. We have assumed that there is a crystal detector in the antenna which has the property of allowing the electrons to pass comparatively freely in one direction through it, and with comparative difficulty in the opposite direction. More electrons will be forced through the detecting device when the electrons are flowing in one direction than when they are flowing in the other, and this will have an effect on the detecting device, and give a signal in a manner with which we are all familiar, and do not need to more closely investigate for our present purposes.

It is evident, by symmetry, on our assumption that the antenna is a simple vertical wire, that the energy must flow out uniformly in all directions from it in any horizontal plane. The energy which is transmitted from it is therefore necessarily spread over a very wide area. So sensitive detecting and amplifying devices are available to-day, however, that it requires only an exquisitely small amount of received energy to give satisfactory signals.

We have thus described very briefly a simple form of electromagnetic transmission. The very simplest case, perhaps, would be one in which a single electron changed its motion, which in turn caused a corresponding change in its field, and thus affected the motion of another single electron which we could consider as the receiving device.

But our discussion has not told the complete story, for evidently not only will the electrons in the receiving antenna be affected by the motion of the electrons in the transmitting antenna,

but every other partially free electron in the vicinity will to some extent be affected. There are, of course, tremendous numbers of partially free electrons present, not only in the material in the earth, but also in the air itself. This is particularly true in the upper strata of the air, in which the action of sunlight is supposed to partially disassociate the atoms of the gases making up the air.

Every partially free atom will tend to be somewhat affected in its motion as a result of the changes in field caused by the sending station, these motions being subject, of course, to whatever constraints surround that particular electron. That is, if the electron is in a conductor, its constraint in general is that it must confine its motion to the body of the conductor. The changes in motion of these electrons will cause changes in the fields which they cause, and these changes will be added to the existing changes in field caused by the sending antenna.

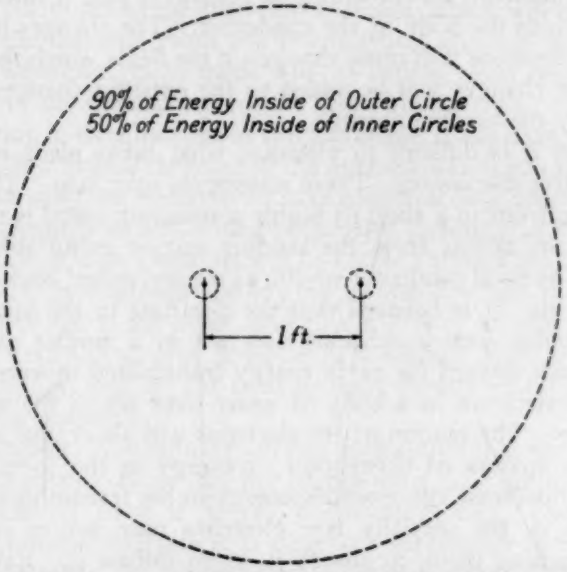
Again it is difficult to visualize what takes place without a quantitative discussion. These statements may help. The action of the electrons in a sheet of highly conducting metal is to largely prevent any action from the sending station going through the metal. The good conductor would, as we say, reflect back the wave reaching it. It is believed that the electrons in the upper strata of air under some conditions may act in a similar manner to reflect back toward the earth energy transmitted upward. Similarly the electrons in a body of water over which the waves are travelling. The motion of the electrons will also cause in general a certain amount of dissipation of energy in the form of heat. This will decrease the available energy in the transmitted wave.

That is, the partially free electrons may act to reflect the wave reaching them, to absorb it, or to diffuse it. Every radio engineer is familiar with the differences in radio transmission between daylight and darkness, and in the frequent erratic action of radio transmission due, presumably, to such effects of partially free electrons.

We are now in a position to see more clearly just what we do in wire transmission as compared with radio. In wire transmission we take deliberate advantage of this fact that the flow of electromagnetic waves is affected by the action of all partially free electrons in the region the waves are traversing. We do this by running a conducting wire between the sending and the receiving station. This conducting wire gives us, then, partially

free electrons uniformly disposed along a path between the sending and receiving stations, and free to move back and forth in the conductor. The electromagnetic waves, as they travel along, set these partially free electrons in motion, and the changes in field caused by this motion add to the changes in field caused by the original disturbance. It is beyond the scope of this paper to show, but it is a fact that the action of these electrons in the wire is just such as is required to limit a large part of the energy in the wave to a region closely adjacent to the wires, and to guide

FIG. 1.



Distribution of the energy transmitted with No. 8 B.W.G. open wire circuits.

it along the wires to its desired destination. To indicate how effective is this guiding action of wires, there is shown in Fig. 1 a diagram of the cross-section of two wires of the sizes used in the longest telephone circuits. The distance between the wires is one foot, which is the usual separation in such circuits. You will note an inner set of circles, which is so drawn that 50 per cent. of the energy is transmitted within the space which they enclose. Ninety per cent. of the energy is transmitted within the outer circle, and practically no part of the energy is transmitted within the wires themselves.

One question which is naturally asked is why, if the electrons move in the wires and electrons are points of tremendous energy density, it is still true that the transmission of energy takes place almost entirely outside of the wires? It should be noted in this connection that in an alternating current system the electrons merely oscillate back and forth so far as transmission is concerned, the net result of their motion being zero. Even in a direct current case it is evident in a system of this kind that as many electrons leave the terminal load as enter it. It is not then a transmission of energy, in a sense of large amounts of energy being associated with electrons and electrons being moved from one point to another, but it is the transmission of energy caused by the readjustment in the fields due to the motion of the electrons at the sending end. The energies in the fields travel at a tremendous speed as compared with the rate of motion of the electrons themselves.

It is of interest to note that the diagram of Fig. 1 represents the conditions very closely, whether the currents being transmitted over the circuit are direct currents, ordinary voice frequencies, or frequences as high as hundreds of thousands, or even millions per second.

In this discussion we are, of course, not attempting to give any picture as to just what is happening in the wires themselves. The free electrons undoubtedly have a considerable erratic motion in addition to the motions which we are interested in. The motions along the wires which are important to us are the average motions of the total mass of electrons.

In closing, it will be of interest to consider briefly the practical importance of thus guiding electromagnetic waves.

For the transmission of power for electric lighting and power purposes it is evidently necessary from the economic standpoint to carefully conserve the power and transfer it with small percentage losses directly to the users. It would be fatal to such a system to allow a large part of the energy to flow out in all directions to regions where it could not be collected and used. Only by means of the wire guides, therefore, has power transmission been satisfactorily accomplished.

For communication purposes, however, we have a quite different matter, because the total amounts of energy involved are

small, and it is not so important to conserve the energy, so long as the amount which reaches the receiving point has approximately the same wave form as was given it at the sending point, and so long as it is of sufficient size to be large compared with any noise

FIG. 2.

1200-pair cable fanned out. The cable contains 2400 wires. The outside diameter of the lead sheath is 2½".

energies which may also be received simultaneously at the receiving point. If these conditions are fulfilled, then the received energy may be amplified until it has the necessary volume to be heard and understood.

For this reason radio has a very definite and important field in communication. It evidently has a large advantage from its

very nature, for broadcasting purposes where it is wished to reach any one of a large number of receiving points spread over a considerable area, or where it is desired to reach points, such as vessels at sea, or places shut off by natural barriers across which it is difficult or impossible to place the guiding conductors.

For communication purposes in which each call is between two people who wish to speak only to each other, as is the case with the great bulk of ordinary telephone communications, the more economical handling of the energy in the guided wire systems and the simpler apparatus involved results in general in much lower costs for spanning given distances. In addition, there are two other advantages of the wire-guided system which are generally controlling. First, space is full of erratic fields due to natural effects, such as lightning discharges. It is not surprising that this should be so, when we consider the large amounts of energy constantly being transmitted through space from the sun, and the effect of this on the atmosphere. These erratic fields cause a large amount of noise which we know as " static " in radio reception. In wire transmission, however, the message is confined to so narrow a channel in space, and this channel can be so balanced that there is comparatively an insignificant amount of effect from such erratic fields in the wire system. Second, where it is desired to transmit a large number of messages, it is necessary to prevent these messages from spreading out and interfering with each other. Under these conditions the extremely narrow space occupied by each message in wire-guided transmission systems is of great importance. It is possible, for example, to transmit commercially within a telephone cable of 2⅝ inches diameter as many as 1200 simultaneous conversations, the different channels being so nicely balanced with respect to each other that not more than a few millionths of the energy in any one gets into any other. Fig. 2 shows a picture of a short piece of cable of this type with the wires " fanned " out at one end of it.

As a fitting closure to this paper, it would be interesting to show some pictures of the communication and power wires which extend over and tie together every part of the country in a tremendous network. It is quite impossible to do this, however, with maps or diagrams which can be satisfactorily reproduced on any reasonable scale for printing.

An Electrical Method for Tracing Stream Lines in the Two-divisional Motion of a Perfect Fluid. E. F. RELF. (*Phil. Mag.*, Sept., 1924.)—The two-dimensional stream lines in a fluid without viscosity and the equipotential lines in an electric field are both represented by the same equation $\nabla^2\phi = 0$. One way to get the stream lines of air about an obstacle is to solve the above equation. Another way is to put a conductor in the shape of the obstacle in an electrostatic field and then to map the equipotential lines about it. If a rather poor conductor, such as water, surrounds the conductor, the results will be but little modified.

A concrete tank, five feet long, half as wide and one-fourth as deep, was filled with water from the spigot. "On the two longer sides are mounted thin sheets of aluminum, and the metal model of the obstacle to be studied stands in the centre of the tank." The maintenance of the aluminum sheets at a constant difference of potential did not give good results. Instead they were connected to an alternating circuit of audible frequency. Two exploring electrodes were used. One was placed at any desired point in the tank, while the other was carried on a pantograph that had a second point, which repeated the motion of the exploring electrode. The two electrodes were connected to a low-frequency amplifier and the experimenter wore headphones joined to the output side of this apparatus. He moved his exploring electrode around until the sound ceased. Then the electrodes were both situated on the same equipotential line. He located the point by means of the pantograph and proceeded to find and fix other points on the same line, the one electrode remaining in its former position. A diagram is given of the steam lines about a flat plate with its length inclined at 45° to the direction of flow. The lines given are alternately determined by the experimental method and by the solution of the equation. They fit together well even near the edges of the obstacle. Rapidity of solution is claimed for the method. G. F. S.

Some Electrical Properties of Liquid Sulphur. D. H. BLACK. (*Proc. Cambridge Phil. Soc.*, Vol. xxii, Pt. iii.)—The viscosity of melted sulphur reaches a minimum between 150° and 160° C., then goes up rapidly to a maximum at 200° and becomes less for higher temperatures. The electrical resistance was found to follow just about the same course, attaining minimum and maximum values at 160° and 187°, respectively. From the effect of time on the current passing through the sulphur, it was concluded that polarization sets in. The author offers this explanation that the yellow liquid sulphur predominates up to 160° and has a less resistance than the brown variety of 200°. As, therefore, the yellow form turns into the brown, the resistance increases. He further holds that conduction in liquid sulphur is electrolytic in character. When the current starts, one allotropic form is deposited on one electrode and the other form upon the second electrode. This raises the resistance of the liquid as a whole. G. F. S.

A SINGLE STRAIGHT CONDUCTOR AS A NEW FUNDAMENTAL.*

BY

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Member of the Institute.

THE writer has long maintained that the most basic fundamental is a unit length of straight conductor removed from all others. To start with the complete circuit as an electrical fundamental leads to very useful results and is invaluable in many if not most of the usual cases, but in a search for the real fundamentals, it misleads rather than leads. There is no such thing as a fundamental complete circuit. The conception of a complete circuit as a fundamental, when applied beyond its proper sphere, has led many able men to embarrassing conclusions which were contrary to the facts, and confuses rather than clarifies many problems. It also discourages the student. The calculations of an engineer harnessing a water power are not concerned with the complete circuit of the water from the seas to the high lands.

It has been maintained, and perhaps even taught, that according to existing laws the total stored energy in and around a unit length of an infinitely long, straight, current-carrying conductor, isolated from all others, is infinite. The algebraic expressions for the self-inductance of such a part are involved, depend on conditions, and are only approximate. To extend a non-rigid formula to infinity is exterpolation, which is only more or less justified guessing; to exterpolate to infinity a formula which is known to be only approximate, may lead to mathematical absurdities.

In order to try to find real fundamentals with energy (instead of forces) as a fundamental physical quantity, the writer has made the following calculations of the energy stored in a unit length of such a straight conductor, by a direct method, based purely on mechanics, and on only such electrical formulas as are based on the same kind of a conductor; hence the method is quite independent of the usual self-inductance factor and of the "complete circuit" handicap. As it involves no limitations or restrictions, other than the conductor being straight and removed from all other circuits, it is mathematically rigid and not only approximate or empirical.

* Communicated by the Author.

Other than that it is electromagnetic, little is yet known positively about the physical nature of this energy, but being energy it must have its equivalent in a mechanical force multiplied by a distance. Some of it is also exterior to the conductor, but in the writer's opinion all external energy must manifest itself in some way (presumably by pressures) in the material of the conductor from where it originated and with which it is in some way intrinsic, analogously to the attachment of the atmosphere to the earth. But this need not be assumed, as it is proved below. Energy leaving its origin as waves or radiation or corona effects is not included here.

In such a conductor Northrup has shown, in a very able paper (*Phys. Rev.*, June, 1907, p. 474), that the radial, mechanical, inward pressure in the interior of the conductor of radius R is $p = i^2(R^2 - r^2) \div \pi R^4$ (the well-known "pinch pressure" formula) in which i is the current and r is the radial distance of any point in the interior, from the axis. If all the quantities are in C.G.S. units the pressures are in dynes per square centimetre. A question has arisen whether the r^2 should not be $r^2/2$, in order to include the outside pressure, but after a long discussion there seems to be no doubt that the original is correct, and that it in fact includes a factor which represents the external pressures, as explained below, and is also proved.

While the flux outside of such a conductor, with a steady current, is said to extend to infinity (like our atmosphere, theoretically, at least), it is known that the radial pressure of all this flux on the conductor is a *finite* pressure on the outside surface (as it is with our atmosphere), and is numerically equal to $i^2/2\pi R^2$, in which R is the radius of the conductor, and i the current. But it can be shown that the interior flux immediately inside of the outer surface exerts an exactly equal amount of pressure outward, thus exactly balancing the pressure from the outside, leaving a zero effective pressure on the outer surface. But this interior flux is the very basis of the evolution of the Northrup expression; hence the mechanical effect of the exterior flux is included in this expression as a pressure, as proved below. Were there no flux on the outside (as with concentric conductors), or were the outside flux distributed differently, as by neighboring conductors, the distribution of the flux in the inside would evidently be quite different.

The method is based on the calculation of the stored energy from final, static, pressures in the material. To do this it is necessary to know the law of the relation between the energy and the final pressures, which law is different in different cases. In the simplest case of a pressure lifting a weight the law is: pressure × area × distance = energy. In this case the pressure or force (force = pressure × area) is independent of the distance through which it has acted, hence the final pressure can correctly be taken to calculate the energy stored in a movement over a given distance. But in the case of a spring, compressed air (at constant temperature), torsion, expansion of a rod by heat, etc., the pressures vary with the distance; starting from zero pressure, the energy calculated from the final pressure is then only half that from the above formula. It is therefore of importance to know what the law is, in determining the energy from the final pressures in the Northrup formula.

The present method of calculating the stored energy consists of three steps. Consider first the radial pressures on a unit length of the long conductor. Let the circular section be considered to be divided into infinitely thin annular parts, or rings, in each of which the radial pressure is that given by the Northrup formula. In calculating the energy in each of these annular parts, it is necessary to know the law above referred to for the relation between the final pressures and the energy. But this is assumed, for the moment, as not yet known; hence the simplest law, energy = force × distance, may be assumed tentatively, and its correctness tested later by experiment; if it is then found to have been incorrect, another law can be tried similarly until the correct one is found.

According to this tentatively assumed law, the energy in each annular part is force × distance, hence it is the pressure (from the formula, for the radius r of that ring) times the cylindrical area of that ring, times the distance dr, that is, energy $= 2\pi prdr$. Substituting for p its value from the Northrup formula, a simple integration between the limits $r = o$ and $r = R$ gives the total energy as $i^2/2$ ergs for this unit length.

But it is not easy to test this experimentally to find whether the assumed law was correct, as the pressures are radial, and an assumed radial contraction makes the assumed constant radius R a variable. But if a similar calculation is made assuming these

pressures or forces to be parallel to the axis (as though the conductor were a liquid), the surface being now the cross-sections of these annular parts, and the distance the length of the axis (unity in this case), the total energy will be found to be the same, $i^2/2$ ergs, as might have been expected. This is the second step, showing that quantitatively the pressures may correctly be regarded as though they were axial.

But in this second case it is now possible to find (by integration) the equivalent total axial force in dynes of all these different axial pressures. It will be found to be half the maximum pressure at the centre, the curve of the pressures being a parabola. As the pressure formula will be seen to be independent of the axial length, the axial pressures and this total force are the same in an infinitely thin cross-section of the cylinder. This alone seems sufficient to prove that the tentatively assumed pressure-energy law was the correct one, making the third step unnecessary, but it may make it clearer to describe this step also, and it is confirmatory. Its only purpose is to prove that law and to confirm that the calculated energy in the first and second steps is the total, hence includes that on the outside also.

In the third step, the experimental one, let this total force be imagined to act axially so as to raise a weight through an axial distance of one unit (one cm.), say by supposing the conductor to be a liquid like mercury, though here assumed to be without weight. This is similar to an action which takes place in hundreds of electric furnaces. The total energy in this external work is evidently force $\times$ distance and the force does not vary with the distance. This energy comes from the source of the current and the circuit has thereby been lengthened one centimetre. This weight may be assumed to be a flexibly connected copper terminal resting on the mercury surface so as not to have any counter-pressure from above, and it is assumed that the additional mercury is supplied from a reservoir without pressure.

But according to Kelvin's well-known law, when a circuit does external work, as in this lengthening of itself against an opposing force, the energy supplied by the source is *twice* the work done externally, constant current being assumed. Or, in other words, when the circuit does any external work it stores up an equal amount of energy in the circuit. Now the only stored energy which has been added is that in and around this increased

length of one centimetre, that stored in the various parts of the rest of the circuit of course remains the same, as constant current was assumed. This Kelvin energy, which has been added, is, of course, the *total* stored energy intrinsic with that part, hence includes that on the outside also.

It therefore follows that the *total* stored energy (inside of the conductor and outside) intrinsic with, or corresponding to, a unit length of the conductor, is equal to that total force multiplied by that distance; and as that force was determined from the final pressures, it follows that the assumption tentatively made in the first and second steps concerning the law of the relation of the final pressures to the energy, was the correct one to use, in electromagnetic pressures and energy; that is, that final pressure × area × distance = energy, is the proper law in this case, as in the raising of a weight. Hence the calculations in the first and second steps are quantitatively correct, and the total energy stored per cm. is $i^2/2$ ergs. It is therefore not infinitely large, as has been claimed, but on the contrary quite small.

The quantitative result that the stored energy is $i^2/2$ was obtained entirely from the first step, under a tentative assumption which was proved by this third step. It therefore is quite immaterial according to what theories the force in the third step is produced (the Kelvin energy law suffices), the chief question settled by this third step is, whether, in adding more energy, the pressure increases, as it would with a spring action or compressed air, or whether it remains constant, as in lifting a weight. It is well known that with liquid conductors, in many electric furnaces of the "pinch effect" type, the cross-section of the conductor remains constant while there is very strong and rapid longitudinal motion; hence the Northrup radial pressures remain constant while there is considerable axial motion with a steady power input, which again proves the law of the relation of the energy to the final pressure to be like that of lifting a weight and not like that of compressing a spring.

In the M L T system the physical dimensions of the square of a current are the same as those of a force, hence when multiplied by a length (the length of a conductor) the dimensions are those of energy. The dimension of a self-inductance is that of a length.

It seems that it has long been known that the energy stored

in the inside of a unit length of a conductor is $i^2/4$ ergs, under the same conditions of a long, straight conductor independent of neighboring currents; hence of the total energy stored, half is in the inside and half outside. Both, of course, increase proportionately with the length. Neither of them involves the radius and they are therefore the same for any radius of wire. This independence of the radius of the conductor, although at first surprising, is to be expected from the usual formulas, because the radius of the circuit or length of wire is now infinite, and compared with infinity the much smaller radius of the conductor is negligibly small, and it is therefore immaterial what it is. It is similar to the allowable process of neglecting the second differential.

That the energy stored in the inside of a conductor is $i^2/4$ ergs per cm. of length is easily obtained by integration from the field strength H in the inside, and the Maxwell stress formula $H^2/8\pi$ by applying the same law as the one used above for the relation between the final pressures and the energy. This at first thought seems to disagree with the writer's result $i^2/2$, which is just twice as great. It would have been more correct to have called the former that part of the energy which *resides in* the conductor. The former is based on the flux intensity H inside of the wire and takes into account only the radial pressure of this flux *toward* the centre. But from the inside flux near the periphery the Maxwell formula calls for an equal and opposite radial pressure toward the outside, and this pressure likewise represents energy, namely, that on the outside.

In a circle of flux (like that in the inside of a wire) the Maxwell stress results in a real mechanical pressure at the centre, as is very evident in many electric furnaces, but the equal and opposite pressure (or stress) of the flux toward the outside can be balanced only by other flux, a solid body (without current) cannot react against or confine a steady flux. But it can easily be shown that the flux intensity immediately outside of the conductor is exactly equal to that immediately inside of its surface. Hence this outward pressure of the inside flux is exactly balanced by the radial inward pressure of the outside flux, as was stated above.

This radial pressure from the outside flux was not taken into account in obtaining $i^2/4$ as the energy residing in the inside

as described above, as it was based only on the inward pressures of the flux intensity H instead of on the total mechanical inside pressures (in the Northrup formula) which the writer used. It can easily be shown that the inward radial pressure on the periphery from the outside is $i^2/2\pi R^2$ dynes per sq. cm., which is just half the total at the centre. It would seem that this alone is sufficient proof that half of the total stored energy is outside of the wire, making the total twice the known, accepted figure for the energy residing in the inside; this, if sufficient, would make the above detailed proof superfluous.

This shows again that although half of the total energy resides outside of the wire, yet the forces involved in this outside energy have their abutments or anchorages in the material of the conductor, and that therefore the energy stored outside manifests itself inside where it can be calculated and measured and, of course, cannot be infinitely large, as was claimed by some.

It is of interest to note that if the radial pressure from the outside flux, namely, $i^2/2\pi R^2$, in dynes per sq. cm. on the outside surface, be assumed to act as a constant radial pressure to the centre (the vanishing point), a simple integration shows that the energy represented thereby is the same $i^2/2$ ergs per unit length of wire.

A general argument, which may not appeal to the orthodox, and is not offered as a definite proof, may be based on the fact that this stored energy resides in the flux and not in the current. The material of a conductor confines the currents but does not confine the flux, as no insulator of flux exists. Flux can be confined only by other flux; the outside flux confines the inside flux; if the forces did not balance there would be a movement or redistribution of the flux and of the flux energy; as there is no such movement the two energies must balance, hence half must be outside and half inside; that inside being known, that on the outside must equal it.

It is of interest to note, and perhaps is to some degree confirmatory of the result, that as the usual expression for the stored energy is $i^2L/2$ in which L is the self-inductance, equating the two gives L = unity, and in the units of the C.G.S. system (assumed for all of the above quantities) the unit of self-inductance is one centimetre, which is the length of the part of the circuit assumed.

The result $i^2/2$ might have been deduced directly without the Northrup formula and without those two or three steps, if it had been definitely known that in such a single, basic, fundamental, straight conductor, removed from all others, the self-inductance of any part is the length of that part; and in the C.G.S. units the length in centimetres is the self-inductance in centimetres. It was also not known, and is even contrary to beliefs (though it seems self-evident to the writer), that the self-inductance of such a conductor is independent of its radius. Having proved the basic result $i^2/2$ by simple mechanics, these two facts seem to have been established thereby. The writer has long maintained that some of our older laws might to advantage be revised by being based on a straight conductor as a fundamental, as advocated by Ampère, instead of on a complete circuit, as advocated by Maxwell. The present case is a good illustration, as it seems impossible to get this fundamental $i^2/2$ result from formulas based on a complete circuit.

It can be shown that for a given current the axial force is independent of the cross-section, and that quantitatively this force $i^2/2$ dynes (which the writer had termed the "stretching force"), multiplied by the length of the conductor, equals the stored energy, in such a fundamental conductor. The self-inductance is then merely the length of the conductor, although generally defined differently.

That the stored energy should be the same for a small wire as for a large one may seem strange in view of the well-known fact that the external flux is far greater for the smaller wire. But a little thought will show that the distances through which the radial pressures from this greater flux act are correspondingly smaller. It is analogous to a lever in action in which the energies at both ends are the same, yet the forces and distances are very different.

It also follows from the above that the self-inductance for such a unit length is independent of the radius of the wire. This seems to conflict with some approximate (non-rigid) formulas that have been used in practice. But the present assumed case of freedom from all external influences is the most basic and most fundamental one, while most, if not all, the other formulas are based on a return circuit, that is, neighboring conductors. Moreover, a self-inductance is physically a length. Attention is

also called to the fact that when expressions leading to infinity are carefully analyzed the real result may sometimes be indeterminate instead of infinity.

Calculating the energy in some numerical cases in the usual way by $Li^2/2$ and using for the coefficient of self-inductance the well-known approximate formula of Kirchhoff $L = 2l \left\{ \log (l/r) - 1.508 \right\}$ for a perfect circle, in which L is in centimetres, l is the length of the centre line of the circle and r is the radius of the wire, both in centimetres, and log means the Naperian logarithm, the stored energy per unit length of circuit in ergs agrees very closely with $i^2/2$ when the circle is large and the wire small, the difference (when less than this) being no doubt due to the fact that the self-inductance formula is not rigidly exact. But for smaller circles the stored energy based on the self-inductance formula increases very rapidly, showing that the neighboring conductors increase the stored energy quite greatly. The $i^2/2$ energy therefore seems to be the smallest possible minimum or limit under perfect conditions of isolation from neighboring conductors.

Bending a given length of a straight current carrying conductor into a circle would store up some new electromagnetic energy, equal to the difference between that in the straight wire and that in the circle (neglecting the energy to bend the wire without a current). The force thus encountered is the one which tends to straighten a circle into the fundamental straight line again, which force the writer, long ago, termed the stretching force, the existence of which is still being denied by some, though by fewer than some years ago.

With such a fundamental value as a basis, a rational formula for self-inductance for a circular circuit might perhaps be developed based on three terms, this fundamental, the additive effect of a decreasing radius of the circuit, and the effect due to the radius of the wire. It has been shown that in circular circuits of a round wire, the flux per unit length is constant, that is, independent of the radius of the circuit, when the ratio of the two radii is a constant. Also that the product of the radius of a wire and the field intensity H just outside of the wire, is a constant per ampere.

Reducing the expression, energy $= li^2/2$, in which l is the

length of a conductor, to the units used in practice, gives $E = 0.00001524\ l\ I^2$, in which E is the stored energy in watt-seconds or joules (one watt-hour = 3600 watt-seconds), l is the length of the conductor in 1000-ft. units and I is the current in amperes. This shows how extremely small it is.

Reducing this same expression $li^2/2$ in absolute units, to amperes, watt-seconds and the metric system, and using 10,000 kilometres as the unit of length, gives $E = 0.5lI^2$. But the practical unit of self-inductance, the henry, is defined as a length of 10,000 kilometres, hence it is immaterial whether one then uses self-inductance units (henrys) represented by L, or length units of 10,000 kilometres; the formula may therefore then be written $E = 0.5LI^2$, which agrees with the usual one for the energy. This shows also that the coefficient ½ is the same for the practical units as for those of the C.G.S. system. Also that it is in such a single, basic, fundamental conductor, uninfluenced by neighboring ones and apparently only in such, that the self-inductance and the length are the same thing. This agreement seems to justify the writer's contention that such an isolated conductor and not the "complete circuit" is the real, most basic, fundamental to be used as a foundation.

It will be seen that the real physical meaning of self-inductance is, that it is the distance through which the current flows in a fundamental conductor, or the axial length of a column of circular flux. Being a purely geometric quantity (a length), it is independent of any flux or flux energy; physically it is the distance (in cm.) over which the force $i^2/2$ of the flux (the stretching force in dynes) has acted in creating the stored energy (in ergs) in a fundamental conductor. If a coil has a self-inductance of n centimetres (or N millihenrys), it means that as far as storage of energy is concerned, that coil is the equivalent of n cm. (or $N \times 10$ kilometre units) of the fundamental straight conductor, of any radius. The fundamental conductor is therefore the absolute unit of reference; the "complete circuit" conception, which has misled so many for many years, would never have led to it.

As our unit of current is based on the flux intensity H (the unit) produced at the centre by one centimetre length of an arc of one centimetre radius, it may be of interest to note here that the H at the centre of any complete circle is just π times that produced at the same distance from the fundamental conductor. This gives

a simple geometric connecting link between the complete circuit conception and the fundamental conductor.

It may also be of interest to note that it follows that for a unit length and unit radius of a fundamental conductor, the total radial force (not pressure) from the outside is numerically equal to i^2, hence is a unit relation in the C.G.S. system; for other radii it is inversely proportional to the radius of the conductor. This when multiplied by half the radius (because it is radial) gives the stored energy $i^2/2$. The total axial or stretching force is independent of the radius; the two forces are equal when the radius is 2, as one distance is radial and the other axial.

The various agreements shown tend strongly to be confirmatory of the correctness of the present method of deducing this $i^2/2$. Also of the writer's contention that the abutments, anchorages, fulcrums, or points of reaction, of all electromagnetic forces, must reside in the material of the conductor. As far as general agreements can be taken as proofs, the present method also confirms Northrup's formula, the Kelvin law, the laws used by Northrup which include the Ampère law of the attraction of currents, and some of Maxwell's quantitative laws which are not limited to complete circuits.

The result $i^2/2$, as the minimum energy, seems to belong to the same class of theoretical limits as the absolute zero of temperature, and the velocity of light.

The present deduction is a further development of a theorem described by the writer nearly thirty-three years ago, in a paper published in this JOURNAL (Vol. 134, 1892, p. 69, and reprinted in other journals), on "The Ampere-Centimetre, a Measure of Electromagnetism." It is now shown that the theorem then stated is strictly correct when applied to energy in and around a fundamental conductor. The flux energy generated by or due to each centimetre of such a conductor is that included in a disc between two planes perpendicular to the conductor and one cm. apart. Although this disc of flux is assumed to extend to infinity (theoretically), the energy in it and the pressures produced by it, per ampere squared, are decidedly finite, and quite small. Flux energy may therefore be correctly measured by half the square of the current multiplied by the length, in such a fundamental conductor. The old idea that the flux in such a disc is contributed to by all the rest of the circuit, is no longer necessary in such a funda-

mental conductor, though of course the longitudinal pressure from the neighboring flux discs (which produces the so-called stretching force) is what confines the flux of each centimetre to its own disc. At the time the earlier paper was published, the writer was handicapped and misled by too much gospel faith in the older laws, and therefore then arrived at only approximate results.

In all the above deductions the permeability has been assumed to be unity, as is done in all such basic formulas.

Summary.—A single, straight, conductor, removed from all others, is a true fundamental and has the following properties:

The total energy stored in and around it is proportional to its length, and is independent of its diameter; half of this energy resides inside and half outside. Its self-inductance is equal to its length, and is independent of its diameter. The self-inductance of any complete circuit (when not non-inductive) may be stated in terms of such a fundamental whose length will then be numerically equal to that self-inductance. The radial and longitudinal pressures are independent of its length, and vary inversely as the cross-section. The radial force is proportional to its length and inversely proportional to its diameter; the longitudinal force is independent of its length or diameter. The field intensity H, at the centre of a circular circuit, is π times that at the same distance from a fundamental conductor.

For a unit length of such a conductor of radius R and with current i (10 amp. units), the quantitative values in C.G.S. units are:

The total stored energy is $i^2/2$ ergs, and is independent of R. The self-inductance is 1 cm., and is independent of R. The radial and longitudinal pressures at the centre are each equal to $i^2/\pi R^2$ dynes per sq. cm., hence proportional to the square of the current, inversely proportional to the cross-section, and independent of the length. The radial force from the outside is i^2/R dynes per cm. of radius, hence is a unit relation for $R = 1$. The longitudinal force is $i^2/2$ dynes, independent of length or diameter.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

ULTRA-VIOLET REFLECTING POWER OF SOME METALS AND SULPHIDES.[1]

By W. W. Coblentz and C. W. Hughes.

[ABSTRACT.]

PREVIOUS investigations of the ultra-violet reflective properties of materials were confined principally to metals and alloys. The present investigation was undertaken for the purpose of obtaining data on the ultra-violet reflecting power of the sulphides of metals having a high metallic lustre.

The materials examined are the sulphides of lead, molybdenum, iron, and antimony in the form of the natural minerals, galena, molybdenite, pyrites, and stibnite.

In previous communications, attention was called to what appears to be a common property of all metals, *viz.*, a low reflecting power throughout the ultra-violet and the visible spectrum, followed by a high and uniform reflecting power in the infra-red.

In contrast with the metals, the results of the present investigation show that the sulphides of those metals which have a high metallic lustre, have their maximum reflectivity in the ultra-violet, followed by a uniform and, generally, a much lower reflectivity in the visible and in the infra-red spectrum.

The sulphides of antimony, iron, and lead (stibnite, pyrites, and galena) have a wide maximum of selective reflection in the spectral region of 310 to 325 $m\mu$. Molybdenite has four maxima of selective reflection at 260, 450, 610 and 690 $m\mu$, respectively.

The reflecting power of duralumin is lower than that of magnalium in the ultra-violet.

Graphitized carbon, at least in the form of the natural Siberian mineral, has a maximum of selective reflection at 260 $m\mu$ in the ultra-violet. Throughout the visible spectrum the reflecting power is fairly uniform, while in the infra-red the reflecting power increases rapidly with the wave-length, attaining a value of 60 per cent. or higher at 12μ.

* Communicated by the Director.

[1] Scientific Papers, No. 493. Price, five cents.

A RADIOMETRIC INVESTIGATION OF THE GERMICIDAL ACTION OF ULTRA-VIOLET RADIATION.[3]

By W. W. Coblentz and H. R. Fulton.

[ABSTRACT.]

IN the present investigation an attempt is made to present the results on a radiometric basis, which seems to be the logical procedure in order to obtain some estimate of the germicidal action of different parts of the spectrum.

The source of ultra-violet radiation was a quartz mercury arc lamp. The test organism was *Bacterium coli communis* suspended in sterile distilled water. This suspension was atomized uniformly over the surface of a Petri dish, containing hardened sterile beef-peptone agar, and then exposed to ultra-violet radiation.

An investigation was made (1) of the spectral range of bactericidal action, (2) of the effect of varying the intensity of the exciting light, and (3) of the method of exposure, whether continuous or intermittent.

From the various experimental data it appears that germicidal action is produced by ultra-violet radiation throughout the spectral range extending from the very short wave-lengths (Schumann rays) to and including 365 mμ. The shortest rays have the most violent lethal action, which decreases in intensity with increase in wave-length.

The long wave-length limit of abiotic action is not well defined. Prior to this investigation it was generally assumed that the long wave-length limit of abiotic action is in the region of about 297 mμ. In the present investigation, when the time of exposure was sufficiently prolonged, killing of bacteria was obtained through screens which transmitted ultra-violet radiation of wave-lengths longer than 297 mμ, including the 365 mμ line. But no abiotic action was obtained through screens which did not transmit the 365 mμ or shorter wave-lengths.

Tests were made to determine the abiotic action of ultra-violet radiation when the total exposure is applied (1) continuously and (2) intermittently with short or long intervals of rest. No difference in the density of the growth of bacteria could be observed whatever the method of exposure. From this it appears that the intermittent exposure does not have a latent effect, either in stimu-

[3] Scientific Papers, No. 495. Price, twenty cents.

lating growth or in continuing the lethal action, during the intervals of rest, and that the killing effect is cumulative.

On low intensities the killing action is greatly retarded. For example, using an intensity of $I \div 50$ it was necessary to expose the inoculated plate for 75 to 80 seconds (instead of 50 seconds) in order to secure the same killing effect as when using unit intensity and unit time. On still lower intensities there are some (although not thoroughly verified) indications of stimulation instead of lethal action.

It is shown that the energy value, of the most active germicidal radiation from the quartz mercury arc, of wave-lengths 170 to 280 $m\mu$, required to kill a bacterium is very small, being of the order of 19×10^{-12} watt or 4.5×10^{-12} gr. cal.

A further deduction is that, in order to produce a rapid abiotic action (in one second) the radiant flux of this germicidal radiation must exceed a certain threshold value, which is of the order of 25 microwatts per mm.[2] This is obtained at a distance of about 15 cm. (6 inches) from a 110-volt mercury in quartz arc lamp consuming about 320 watts (80 volts, 4 amps.) in the burner.

TABLES FOR THE CALCULATION OF THE MUTUAL INDUCTANCE OF CIRCUITS WITH CIRCULAR SYMMETRY ABOUT A COMMON AXIS.[1]

By F. W. Grover.

[ABSTRACT.]

(1) In the calculation of the inductance of circular circuits a knowledge of the mutual inductance of two coaxial circular filaments is of fundamental importance. From this simple case formulas for the inductance of circular coils, rings, and solenoids; the mutual inductance of coaxial coils and solenoids; and the constant of the Lorenz apparatus have been obtained by integration. Even in cases which are too complicated to allow the integration to be performed, numerical results of no mean accuracy may be secured by mechanical quadrature of formulas for the simple case.

(2) For these reasons this basic case has received considerable

[1] Scientific Papers, No. 498. Price, ten cents.

attention and many formulas have been derived. Of these the majority are in series form and the computer is obliged to exercise care in the selection of a formula which shall converge with sufficient rapidity to be suitable for the individual case in question. Furthermore, if many calculations have to be made, the actual labor of computation involved is considerable.

(3) In the light of these facts, tables to simplify the obtaining of numerical results fill a very real need. A short table for this purpose was prepared by the author of the present paper in 1917. Recently, valuable tables and charts by Curtis and Sparks have appeared which allow an accuracy of one-tenth of 1 per cent. to be readily attained in the calculation of the inductance by simple interpolation from the tables.

(4) In the present paper further tables are given for obtaining the mutual inductance of two coaxial circular filaments. The method of calculation differs from that adopted by Curtis and Sparks, use having been made in their preparation of the tables of elliptic functions recently published by Nagaoka and Takurai.

(5) To calculate the mutual inductance of any chosen pair of circles, it is only necessary to compute a modulus from the radii of the circles and the spacing between their planes. With this modulus as argument, a factor f is taken from the table by interpolation and the mutual inductance is given by the product of this factor and the geometric mean of the radii. An accuracy of one part in 10,000 is readily attained.

(6) For the important case of two circles of *equal* radii the same table may, of course, be used, but a simple modulus may be calculated, namely, the ratio of the common radius to the distance between their planes. Two tables are given which show the value of f for equal circles, one with the above parameter as argument and the second with its reciprocal as argument. By this means the parameter to be used is always less than unity.

(7) In the limited regions where the circles are very close together, or very far apart, interpolation in these tables becomes difficult. This inconvenience is, however, readily overcome by the use of short auxiliary tables in which the logarithms of the parameter already discussed are selected, instead of the parameters themselves, with the result that second differences are negligible for the regions in question.

EFFECT OF HOT-ROLLING CONDITIONS ON THE PHYSICAL PROPERTIES OF A CARBON STEEL.[4]

By J. R. Freeman, Jr., and A. T. Derry.

[ABSTRACT.]

IN order to obtain more exact and comparative data on the individual effects of the more important variables of rolling on the physical properties of steel, an investigation was carried out, using a specially prepared heat of steel and rolling in an experimental rolling mill. The five variables selected for study were: Initial temperature of rolling, finishing temperature of rolling, total reduction, pass reduction, and rolling speed. The steel used was electric-furnace steel (0.46 per cent. carbon) cast with hot top and under carefully controlled conditions to insure homogeneity. A survey of the chemical homogeneity was made by chemical analysis of drillings taken from different parts of the ingot preliminary to any rolling. The experimental mill in which the steel was rolled was a two-high 16-inch plate mill with suitable controls. All heating was done in a gas-fired semi-muffle furnace, the temperature of which was controlled with suitable thermocouple and potentiometer equipment. The finishing temperature was observed with an optical pyrometer.

The values used for the variables studied are given in the following table:

Initial Temperature.	Finishing Temperature.	Pass Reduction Per Cent.	Total Reduction.	Peripheral Roll Speed Ft. / Min.
° C.	° C.			
1200	1000	12	7 to 1	250
1130	900	8	5 to 1	175
1060	850	5	3.5 to 1	125
1000	750	3	2 to 1	85
950	700	2	1.3 to 1	....
900	650	...	.....	....

The physical properties of the rolled plate determined were tensile properties (ultimate strength, yield point, proportional limit, elongation, reduction of area) impact resistance, density, microstructure, Brinell and Scleroscope hardness. For purposes of comparison the above properties of the steel "as cast," and "as cast" heated but not rolled, and normalized after rolling were determined.

[4] Technologic Papers, No. 267. Price, ten cents.

The steel was rolled in one direction only in order to determine the effects of unidirectional rolling on the relative mechanical properties in directions transverse and longitudinal to the direction of rolling.

The results obtained indicate that the total reduction and finishing temperature are the most important factors in rolling. A change in these conditions has a greater influence on the mechanical properties of the steel than either of the other three factors studied, which were found to have very little influence. An increase in total reduction decreases the ultimate strength and increases the yield point, ductility and impact resistance. A slightly lower ultimate strength, but greater yield point, ductility, and impact resistance were obtained with a finishing temperature of 700° C. as compared with a finishing temperature of 1000° C. Unidirectional rolling causes a slight difference in the mechanical properties of the steel between the longitudinal and transverse directions. The properties in the transverse direction are, in general, inferior. Normalizing the rolled plate tends to eliminate all differences produced by the difficult rolling conditions.

The density of the steel is the same in the cast and rolled conditions and is not affected by rolling conditions.

SPECIFICATIONS FOR CONSTRUCTING AND OPERATING HEAT-TRANSMISSION APPARATUS FOR TESTING HEAT-INSULATING VALUE OF FABRICS.[5]

By P. S. Sale.

[ABSTRACT.]

THIS paper is a supplement to a Technologic Paper, issued some time ago, which deals with the general problem of "Heat Insulating Properties of Fabrics." Specifications for constructing and operating the apparatus are given so that it may be duplicated and its use thus extended by those concerned.

Detailed drawings of the heat-transmission apparatus for testing fabrics, electric wiring diagrams, and an example of the temperature balance required for the several parts of the apparatus during a test are included as a part of the specifications.

Under the heading "construction," the size, shape, and assembly of the parts are given. A bill of materials is furnished, and

[5] Technologic Papers, No. 269. Price, ten cents.

the function of the material especially selected for the several parts of the apparatus is explained.

Under the subject "layout and assembly," the essential details are treated part by part to assure good construction and assembly of the apparatus.

Under "operation," a complete electric wiring diagram is presented which covers diagrammatically the three sets of electric circuits—(1) power; (2) thermocouple; (3) potentiometer. Brief descriptions of these circuits follow:

(1) Two power sources are employed in heating the resistance grids. A low-voltage a.c. source is used for preliminary heating, while a 12-volt storage battery source is used for final heating on account of its steady voltage, which is desirable. The current supplied to each of the four resistance grids is regulated independently by separate rheostats. An ammeter is used in these circuits for approximate current readings, while a standard resistance, in connection with a potentiometer, is used for precise current readings. With these provisions for regulating the current in the main and guard grids, the heat dissipated therein is under control, and is uniformly distributed by good conducting copper cover plates to which copper-constantan thermocouples are attached for determining temperatures.

(2) The wiring diagram shows two sets of these copper heat-distributing plates, with thermocouple wires leading to local selector switches, thence to a master selector switch, thence to a potentiometer. By this arrangement of thermocouple circuits, quick temperature determinations can be made of the several plates and a precise temperature balance between the several parts of the apparatus is obtainable. The temperature readings are in terms of millivolts, so a thermocouple calibration chart (temperature *v.* millivolts) is used to obtain the temperature.

(3) The temperatures and the final current readings are made in terms of e.m.f. by a "null" or balance potentiometer method. The wiring diagram for the potentiometer, used in these experiments, is taken from the manufacturer's catalogue and reference is given thereto. It is stated further that any type of standard potentiometer might be employed

The paper presents an example of temperature balance obtainable with the apparatus, between the centre and its guard heaters. This balance is referred to as a necessary guard at the edges

and bottom of the main heater, which insures no heat loss, flow, or exchange, at these locations, from the main heater. Thus all heat supplied the main heater flows perpendicularly from the top surface through the test specimen which covers it, and unidirectional heat flow is obtained from the test section heater. An example of computation is also given from readings taken after adjusting the apparatus to such a temperature balance. It takes an hour or two to bring the apparatus to the required temperature balance, but only a minute or so to take the final readings which are used in computation.

The apparatus in its present form is recommended for making the heat-transmission tests of fabrics under still air conditions. Provision is now being made for testing the effect of breezes blowing across the surface of the test specimens. The additional equipment for these tests will probably be simply a wind-tunnel or jacket to be placed over the apparatus and provision made for measuring the quantity and temperature of the air.

RECOMMENDED SPECIFICATION FOR QUICKLIME AND HYDRATED LIME FOR USE IN THE ABSORPTION OF CARBON DIOXIDE.[6]

CARBON DIOXIDE may be removed from mixtures of gases by absorption, using lime. Two methods are employed. Hydrated lime may be moistened and spread out in thin layers, over which the gas to be purified passes or the gas may be scrubbed with a milk of lime, made from either quicklime or hydrated lime. Quicklime should contain not less than 90 per cent. available lime and hydrate not less than 85 per cent. available lime. Hydrate should have a fineness of 97 per cent. through a No. 200 screen.

UNITED STATES GOVERNMENT MASTER SPECIFICATIONS FOR INK: RECORD AND COPYING (C182), WRITING (C183), RED (C184), AND FOR STAMP PAD (C185).[7]

[ABSTRACT.]

THE first of these is the ink that has been used for many years as the "Government standard." It is a blue-black iron gallo-tannate ink, of about twice the strength of the best commercial inks. Because it contains such a large amount of iron gallo-

[6] Circular No. 189. Price, five cents

[7] Circulars Nos. 182, 183, 184 and 185. Price, five cents.

tannate in order to give permanence to the writing, it must also contain a relatively large percentage of free acid to hold the iron in solution. There have been innumerable complaints about its corroding and clogging pens and forming deposits in ink wells. Although these complaints are well founded, it seems necessary to continue the use of this ink for documents of importance. Copying ink is so little used that no specification for it was drawn up. Fresh writing with the record ink will give a good copy.

For ordinary purposes there is no good reason why a more dilute and less acid ink should not be used. The writing ink called for in the second specification is of half the strength of the record and copying ink. It is of about the same concentration as the better brands of writing fluid sold to the public and, like them, is suitable for use in fountain pens. There should be no complaints about ink that meets this specification. The writing will not be as permanent as that made with the record ink, but under ordinary conditions it should be legible for many years.

Included under writing ink are concentrated inks, and ink powders and tablets. All of these, when mixed with the proper amount of water, must produce writing ink of the same quality as the fluid, that is, it must be blue-black iron gallo-tannate ink.

The red ink, for bookkeeping and other writing, and the five colors of stamp pad ink for use with rubber stamps, are solutions of dyes. They can not be expected to have the permanence of iron gallo-tannate inks.

Each of the four specifications gives the formula for a standard ink which must be at least equalled in quality by purchased material. The methods of testing by which samples of deliveries are compared with the standards are described in detail.

THE USE OF UNITED STATES GOVERNMENT SPECIFICATION PAINT AND PAINT MATERIALS.[8]

By P. H. Walker and E. F. Hickson.

[ABSTRACT.]

A BRIEF description is given of the various materials covered by the specifications. It is believed that the existing specifications are sufficient for practically all necessary painting operations of the Government. The system of using semi-paste paint, whenever possible, is recommended and suitable thinning formulas applic-

[8] Technologic Papers, No. 274. Price, ten cents.

able for the average painting condition have been developed. The proper method of breaking up and thinning stiff pastes in oil, semi-pastes, and mixed paints is discussed. The practical application of the various paints to all of the ordinary surfaces, such as wood, metal, cement, plaster, concrete, etc., is brought out and recommendations made. The care of brushes and the brushing of paint is described.

TECHNICAL CONFERENCE OF STATE UTILITY COMMISSION ENGINEERS.[9]

HELD AT DEPARTMENT OF COMMERCE, BUREAU OF STANDARDS, WASHINGTON, D. C., MARCH 2 AND 3, 1923.

[ABSTRACT.]

IN connection with the investigations bearing on the operation and regulation of public-utility services which the Bureau of Standards has been carrying on for a number of years, it has become more and more evident that there should be provided a more effective means of coöperation between the bureau and the engineers of the various commissions. It has also been recognized as very desirable that engineers of commissions themselves have some more or less regular means of making contact with each other and discussing problems of mutual interest. Accordingly, arrangements were made by the Bureau of Standards for a general conference, which was held in Washington on March 2 and 3, 1923. At this conference twenty-three commission engineers, representing fifteen States and the District of Columbia, were present.

The session on March 2nd was held at the Department of Commerce Building and was opened by an address by Hon. Herbert Hoover, Secretary of Commerce, who stressed the importance of greater participation by engineers in the solution of the problems of government.

E. C. Crittenden, chief of the electrical division, presented a general review of the work of the public-utility sections of the Bureau of Standards. This was followed by brief statements by members of the engineering staff of the bureau, describing their respective phases of the public-utility work, which comprises the formulation of safety codes, development of electric-service standards, the study of various problems relating to gas and tele-

[9] Miscellaneous Publications, No. 58. Price, fifteen cents.

phone service, and the mitigation of electrolysis of underground pipes and cables by stray currents from electric railways.

Two papers were then presented on the subject of "Grading of Public Utilities." These papers were followed by a general discussion of the inductive interference problem, which was introduced with a general review of the inductive interference situation. The discussion which followed related largely to general principles, no attempt being made to discuss technical details of the problem.

The subject of "Grounding of Electrical Circuits" was introduced, and this was followed by a general discussion of grounding of electrical systems.

The second session of the conference was held on Saturday, March 3rd, at the Bureau of Standards. Two papers were presented on the subject of the "Public Interest in Heating Value Standards for Gas." The subject of "Conservation of Natural Gas" was discussed in two papers.

Following the first technical session of March 2nd, there was some discussion of the advisability of holding further meetings of this same character, and a committee was appointed to consider the matter. This committee reported on the second day of the conference and recommended that similar conferences be held at such times and places as might be determined, and that for the present the Bureau of Standards continue to act as sponsor for these conferences. The committee also recommended that an executive committee be formed, the chairman of which should be a commission engineer and the secretary a member of the staff of the Bureau of Standards, the purpose of the committee being to provide a representative body with whom the bureau might consult in making plans for future conferences. The plan recommended by the committee was unanimously adopted and an executive committee was elected.

RECOMMENDED MINIMUM REQUIREMENTS FOR PLUMBING IN DWELLINGS AND SIMILAR BUILDINGS.[10]

[ABSTRACT.]

THE report on Recommended Minimum Requirements for Plumbing in Dwellings and Similar Buildings results from a widespread feeling that present state and municipal code require-

[10] Special Publications, Housing Division. Price, thirty-five cents.

ments are in some respects unnecessarily restrictive and that conservation of labor and materials could be effected by scientific investigation of the burdens on such systems and their performance under conditions of use. It is well known that the codes of different localities vary widely and that practices forbidden in some places are successfully employed elsewhere. The benefits of uniform requirements in permitting simplification of plumbing supplies also are stressed.

A committee of sanitary engineers and others was organized for consideration of this subject. It was found that very little scientific data existed upon which recommendations for uniform code requirements could be based. Arrangements, therefore, were made to perform extensive tests with plumbing equipment at the Bureau of Standards in Washington, as a preliminary to the drafting of recommended code requirements. These experiments were carried on for over two years and afforded much valuable data, a detailed report of which is included in the publication. The investigations developed the relative discharge rates of different fixtures and logical methods of predicting the probable peak load on plumbing systems, the results indicating that present customary assumptions are considerably on the side of safety. The hydraulics and pneumatics of partially filled pipe systems were extensively studied. It was found that water falling in plumbing stacks approaches but does not exceed a velocity of about thirty-five feet per second. The experiments disclosed that if certain precautions are observed, the unvented length of horizontal branch waste pipes may be from five to eight feet without danger to trap seals, and tests with complete household systems were carried on, resulting in a series of simplified plumbing systems recommended for use in dwellings. It was found that 3-inch soil stacks were adequate for all demands met with in buildings of the types considered. The committee recommends omission of the house or running trap except under special circumstances.

Throughout the investigation it appeared strongly that a reduction in the number of types and sizes of plumbing supplies would make for great economy in this industry and while this is not itself a subject within the scope of the police power, that greater uniformity of code requirements would assist considerably in efforts now initiated to bring this about.

Consideration was given to the much-discussed subject of plumbing-code administration. The report states that while the effect of poor plumbing design on disease is less direct than formerly believed, the subject in all its branches is not yet fully explored and direct access of vermin from the interior of plumbing systems to that of buildings is sufficiently objectionable to justify public regulation of plumbing work. The committee recommends a competent official plumbing inspector under jurisdiction of public safety authorities, to examine and approve plans and specifications, test and approve plumbing systems, and take such other measures as will make his control of plumbing work effective. The advisability is suggested of substituting certificates of competency for the present licensing system and of permitting owners to install plumbing personally, provided this is done in accordance with the code and subject to official permit and inspection.

The report follows the conventional practice as to quality and weight of pipe and other materials, although extra-heavy cast-iron pipe is recognized as somewhat heavier than necessary for this purpose.

Experiments reported in the Appendix show that gases are diffused with difficulty in unventilated horizontal waste pipes, concentrations varying approximately with the square of the pipe length, and that considerable corrosion effects may be looked for in unventilated pipes more than five feet in length.

The report contains 269 pages of text and over one hundred illustrations, mostly given in connection with the report of experiments at the Bureau of Standards.

PAINTS AND VARNISHES.[11]

[ABSTRACT.]

THIS project is one of an extended series of waste elimination efforts being carried forward by various industries, assisted by the Chamber of Commerce of the United States, the American Engineering Standards Committee, and the Division of Simplified Practice of the U. S. Department of Commerce.

During the war, paint manufacturers, in coöperation with the War Industries Board, adopted as their standard of practice, a

[11] Limitation of Variety Recommendation, No. 1. Price, five cents.

restricted list of colors, tints, and shades of paints and varnishes, as well as of definite sized containers. Concentration of production, distribution, and consumption on this restricted list proved beneficial to all interests. However, since the war a tendency to revert to the former diversity developed, and leading manufacturers and others recommended a reaffirmation of the conservation schedule.

After several conferences with the Division of Simplified Practice, the manufacturers, distributors, and consumers concurred on March 13, 1924, in reëstablishing the reduced list as the recommended standard of practice, to become effective September 1, 1924. It is expected that nation-wide adherence to this list will result in reducing inventories, and idle investment, as well as stimulate turnover and facilitate more economical manufacture and distribution. This confirmation of an established practice, and the consequent limitation against further diversification, provides a definite basis from which a simplification, *i.e.*, an elimination of seldom-called-for and little-used varieties can be developed.

The Mass-spectra of Cadmium, Tellurium, and Bismuth. F. W. ASTON. (*Nature,* Nov. 15, 1924.)—Cadmium fluoride was used in the anode and cadmium rays were obtained that registered on "the most highly sensitized schumannized plates. Cadmium is a very complex element, having six isotopes: 110 (c), 111 (e), 112 (b), 113 (d), 114 (a), 116 (f). The last is isobaric with the lightest isotope of tin. The intensities of the lines are in the order of the letters and agree reasonably with the chemical atomic weight, 112.41. The most striking characteristic of the group is its remarkable similarity to that of tin." Previous attempts to get the mass-spectrum of tellurium had failed, but now an anode with this element in it gave three lines revealing three isotopes of the respective atomic weights of 126, 128 and 130. "Comparison with other lines on the plates suggests that their masses may be less than whole numbers by one or two parts in a thousand, but it seems probable that the mean atomic weight is actually greater than 128, whereas all the later chemical determinations are less than that figure, the accepted value being 127.5. The element tellurium is unique among those so far analyzed, as it seems probable that *all* its mass numbers form members of isobaric pairs. These are shared by xenon, the element of next higher even atomic number." Bismuth gave one line and one line only. "There seems no reason to doubt that bismuth is a simple element of mass number 209, as recent determinations of its atomic weight suggest." G. F. S.

NELA RESEARCH LABORATORY NOTES.*

THE PROPERTIES OF TUNGSTEN AND THE CHARACTERISTICS OF TUNGSTEN LAMPS.

By W. E. Forsythe and A. G. Worthing.

THE results of an extensive study of tungsten, with all the data based on the same temperature scale, are presented under the following subdivisions.

Radiational, Electrical, Thermal, and Mechanical Properties of Tungsten.—For the temperatures for which data are available these properties are shown in figures and tables, for 100° intervals, for a temperature range from 300° K. to the melting point (3655° K.). Many interrelations between the properties are pointed out.

Characteristics of Tungsten Lamps.—This includes a discussion with data of changes with temperature for (1) voltage, current, wattage, candlepower, efficiency, and life of vacuum lamps; (2) dependence of current, voltage, etc., upon filament dimensions; (3) photographic effects, and (4) gas losses.

End Losses.—Losses due to heat conduction from a filament to the leads and supports are discussed and methods are given for correcting them. There is given a table showing filament lengths necessary in order that the central portions of different sized filaments, operating at various temperatures, shall be free from effects due to end losses.

Temperature, Brightness, and Efficiency of Some Commercial Lamps.—Tables are given showing data for commercial lamps.

The complete paper will be published in an early number of the *Astrophysical Journal.*

A New Phenomenon in the Diamagnetism of Gases. A. GLASER. (*Ann. d. Physik*, No. 21, 1924.)—Of all substances gases have been the most difficult to investigate magnetically. This is because of the feebleness of the forces experienced by them in a magnetic field. Up to about 1919 little more could be found recorded concerning the susceptibility of gases than the positive or negative sign, and this was not always certain. Since the year stated, Také

* Communicated by the Director.

Soné and A. P. Wills, with G. Hector, have published in England and in the United States, respectively, very much more sensitive methods that give reliable results.

In the method described in the present paper a quartz thread hangs from a torsion head. To the lower end of the thread is attached a narrow, vertical glass tube, supporting near its upper end a mirror for the reading of deflections, and at its lower extremity a horizontal glass rod 26 mm. long, made of diamagnetic glass to which sufficient cobalt glass has been united to render the whole paramagnetic. This rod is placed between the obtusely pointed pole pieces of an electromagnet, giving a field of 4500 gausses. The gas to be investigated fills the apparatus surrounding the glass rod. With a vacuum in the apparatus and the magnetic field in action, the torsion head was turned until the glass rod occupied a definite position. Then the gas was introduced and the rod brought again to its former position by the torsion head. The gas pressure was reduced to zero step by step and at each pressure the rod was returned to its initial station. This series of observations does not permit an absolute value of the susceptibility to be calculated, but it does furnish a quantitative comparison of the values of this property at different pressures. The absolute values were computed from the absolute determination for H_2 made by Soné.

H, N, and CO_2 were investigated. In all of them the susceptibility was negative (they are diamagnetic) and its numerical value diminished as the pressure grew less. Again with all, the pressure being about atmospheric, the rate of decrease of susceptibility with pressure was linear and such that, were it to continue, at zero pressure there would be zero susceptibility, as is actually true. However, as the pressure goes down, at a different value for each gas the rate of loss of susceptibility is slowed up, so that for certain pressures the magnitude of the susceptibility remaining is three times as great as it would have been had the initial rate of decrease continued. At still lower pressures its rate of decrease once more becomes greater. It is to this change in the rate of decrease of the susceptibility that the author directs attention as to a new phenomenon. The maximum pressure employed seems to have been 900 mm. mercury. Great care had to be taken to ensure constancy of temperature because a change of 1° C. in the glass rod caused a change in its susceptibility equal to the whole value of this property for molecular hydrogen.

The author's opinion of the cause of the new effect is this: "The magnification of the susceptibility to the threefold size can scarcely be interpreted otherwise than as showing that an arranging of the molecules with respect to the direction of the field takes place." At the higher pressures where the susceptibility falls away regularly, the frequency of molecular collision is so great that a molecule does not have time to turn itself into a definite position with respect to the field before it is struck by a neighboring molecule and knocked into a new position. G. F. S.

NOTES FROM THE RESEARCH LABORATORY, EASTMAN KODAK COMPANY.*

INVESTIGATIONS ON PHOTOGRAPHIC DEVELOPERS. II.[1]

SULPHIDE FOG CAUSED BY BACTERIA IN MOTION PICTURE DEVELOPER.

By M. L. Dundon and J. I. Crabtree.

SAMPLES of tank developer which suddenly began to give excessive fog were found to contain sodium sulphide. The concentration of sodium sulphide in two of the fogging developers was approximately 0.005 per cent. and 0.02 per cent. When free sulphur was added, sodium thiosulphate or other polythio salts were formed, but no sulphide could be detected. The formation of sulphide from thiosulphate or rubber in a developer is improbable.

Different organisms are capable of reducing thiosulphate, sodium sulphite and sodium sulphate to sodium sulphide. Certain unidentified fungi and several species of bacteria were found living in the fogging developer. Experimentally in the laboratory by adding yeast or slime, the formation of sulphide in developers was reproduced. The evidence indicates that the sulphide in the fogging developers investigated was formed by reduction of the sulphite by living organisms.

When a developer is used continuously, the dissolved silver precipitates the sulphide as fast as it is formed and no fog is produced. The solvent power of the developing solutions for the silver halides in various emulsions was measured. A developer which gives sulphide fog can be revived by the addition of a small quantity of lead acetate which precipitates the sulphide as lead sulphide, or by developing a quantity of waste film therein. About 0.5 g. of crystalline lead acetate per litre of solution is sufficient in most cases. No substance has yet been found which can be recommended as a preservative against bacterial growth in a developer.

* Communicated by the Director.

[1] Communication No. 219 from the Research Laboratories of the Eastman Kodak Company, and published in *Amer. Cinemat.*, 5:9 (1924); and *Trans. Soc. Mot. Pict. Eng.*, No. 19, 1924.

HANDLING CINE FILM AT HIGH TEMPERATURES.[1]

By J. I. Crabtree.

INFORMATION is given relative to the storage, shipment and conditioning of motion picture film before and after exposure, and the processing of film at high temperatures. Two methods of drying film are described whereby the loosely wound film is placed in a container (1) with dried paper, which absorbs the moisture, or (2) with some deliquescent chemical such as calcium chloride. For high-temperature processing, three methods of preventing excessive swelling of the gelatin are described: (*A*) By the use of concentrated solutions; (*B*) by the addition of inactive salts, such as sulphates or phosphates, to the developer solutions; (*C*) by permanently hardening the gelatin. For hardening, alums are preferred to formalin, as the latter gives trouble from fog and objectionable odors. Chrome alum yields maximum hardening when used as an intermediate bath between development and fixation. When incorporated in a fixing bath, chrome alum rapidly loses its hardening properties. Procedures are recommended for processing motion picture film at 85° F. and at 90° F. In the former, three to four minutes' development in a concentrated developer is recommended, followed by a few seconds' water rinse and three minutes' immersion with agitation in a 3 per cent. potassium chrome alum solution. Any hardening or non-hardening fixing bath may be used after treatment in the chrome alum hardening solution. Washing should be completed in ten to fifteen minutes. For processing at 90° F. the same procedure is used, except that the chrome alum hardener contains 12 per cent. sodium sulphate in addition to the chrome alum. Films processed by these methods will dry comparatively rapidly, as excessive swelling which makes drying slow and difficult will have been prevented. Several miscellaneous hints are given in conclusion relative to the wearing qualities of film processed by the methods suggested, the decomposition of films with age, and ways of avoiding brittleness.

[1] Communication No. 218 from the Research Laboratories of the Eastman Kodak Company and published in *Amer. Cinemat.*, 5: 4, 1924; *Amer. Phot.*, 19: 36, 1924; *B. J. Phot.*, 71: 762, 1924; *Trans. Soc. Mot. Pict. Eng.*, No. 19, 1924.

INVESTIGATIONS ON PHOTOGRAPHIC DEVELOPERS. I.[1] THE FOGGING PROPERTIES OF DEVELOPERS.

By M. L. Dundon and J. I. Crabtree.

THE total fog on a developed film is the complex result of many factors which must be considered separately. The oxidation products of elon and hydroquinone in a practical developer do not cause fog and the recommended method of mixing elon hydroquinone developers is of less importance than was supposed. The fog previously observed from such causes was probably due to substances which are eliminated from present-day American photographic chemicals.

Aerial fog is probably caused by chemiluminescence, and can readily be prevented by the use of desensitizers, either in the developer or preliminary bath. Pinakryptol green is the most satisfactory desensitizer for eliminating aerial fog with elon hydroquinone developers, and is effective in a concentration of 1 : 500,000. Phenosafranine is also satisfactory, while oxidized developers tend to diminish aerial fog. Pyro added to an elon hydroquinone developer is effective in preventing aerial fog, but increases aerial oxidation and is less desirable than a desensitizing dye. The fact that developers conditioned by use give less tank fog than fresh ones has been confirmed and is being investigated further.

Some Problems Relating to Antarctic Sea-ice. R. W. JAMES. (*Mem. and Proc. Manchester Lit. and Phil. Soc.*, Vol. 68, VII, 1923–24.)—"It is well known that water fresh enough to drink may be obtained by melting sea-ice." When sea water freezes pure ice separates out and the concentration of the salt in the solution left is increased. If only a small quantity of solution were concerned the concentration would go on increasing with formation of ice until at −22° C. salt would be deposited along with the ice. On account of the vast volume of water present, this does not occur in the ocean and only ice is formed. But salt solution is entangled among the ice crystals. "Freshly formed ice when melted yields a solution containing from 1.2 per cent. to .7 per cent. of sodium chloride; the actual amount, no doubt, depending on the rate of freezing. Ice which had formed during the winter in which the observations were taken, and had attained a thickness of five feet, had a salinity of .4 per cent.

[1] Communication No. 222 from the Research Laboratories of the Eastman Kodak Company and published in *B. J. Phot.*, 71 : 701, 1924; *Amer. Phot.*, 18 : 742, 1924.

to .5 per cent., while older ice *in situ*, which had certainly been through one summer, still contained .2 per cent. of salt, this being far too much for the ice to be of any use for drinking water." The ice that yields potable water always comes from an old pressure hummock and can be recognized by its spotted appearance in contradistinction to the fibrous structure of new ice.

"Even at very low temperatures, certain of the salts contained in the ice are lost and make their appearance in drops of intensely saline liquid at the lower extremities of icicles hanging beneath the ice-block. These drops of liquid were observed to remain liquid when the air temperature was as low as −30° C., so that they were evidently not mainly common salt."

. How does the entangled salt water escape from a piece of ice so that drinking water can be obtained by melting? Let there be a portion of salt water included in a block of ice warmer than the temperature −22° C., at which solid salt is deposited. Whatever the temperature be, the included solution must be in equilibrium with the surrounding ice. If the temperature rise, some ice will melt, the volume of the inclusion will be larger and the concentration will be reduced to that necessary for equilibrium at the new temperature. It seems likely that the melting of the ice takes place all around the liquid, so that the centre of gravity of the inclusion is neither raised nor lowered by the process. If the temperature fall, ice will form from the solution, the concentration of which increases and restores equilibrium, but owing to the influence of gravity the deposition will not be uniform like the melting: More ice will be deposited at the top than at the bottom, and the centre of the inclusion will sink. It may thus be possible for alternate rises and falls of the temperature to cause an inclusion to pass downward through the ice without the ice ever becoming really porous. A series of observations to test this theory was under way "but they were interrupted by the loss of the ship, and consequently of all means of carrying them out, just at the stage at which they were becoming interesting." The author was a member of the Shackleton expedition in 1915. G. F. S.

Index of Refraction of Calcite for X-rays. C. C. HATLEY. (*Phys. Rev.*, Nov., 1924.)—On a calcite crystal a polished surface was made that formed an angle of about 6° with the cleavage planes. Monochromatic X-rays entered through this surface were reflected from the cleavage planes and again traversed the surface on their way to the air. It was found that they were bent away from the surface, when they left the crystal to go into the air, through an angle of 28.7 secs. From this the refractive index of the crystal is calculated to be less than unity by the amount 2.21×10^{-6}. By a second method a bending on emergence of as much as 1′ 3.6″ was obtained. This gave for the index a value of unity minus 1.94×10^{-6}. The Lorentz dispersion formula gives for the index $1 - 1.91 \times 10^{-6}$. G. F. S.

NOTES FROM THE U. S. BUREAU OF CHEMISTRY.*

COLLOIDS IN CANE AND BEET SUGAR MANUFACTURE.[1]

By H. S. Paine, M. S. Badollet, and J. C. Keane.

[ABSTRACT.]

DATA involving the following criteria and testing methods were obtained in an investigation of the colloids in cane and beet products: Dialysis, ultra-filtration, cataphoresis, gold number, surface tension. Quantitative data were obtained on the quantities of colloids of predominantly emulsoid and suspensoid types in various beet and cane products. The approximate composition of various colloid fractions separated from different factory products was determined. The data obtained have distinct constructive value in connection with efforts to prevent or minimize production of off-color sugar and to control colloid viscosity effects resulting in slow-boiling, retarded crystallization, etc.

NAPHTHALENESULPHONIC ACIDS.[2]

VI. SULPHONATION OF NAPHTHALENE IN THE VAPOR PHASE.

By J. A. Ambler, D. F. J. Lynch, and H. A. Haller.

[ABSTRACT.]

A NEW method for sulphonating naphthalene has been devised in the Bureau of Chemistry. Naphthalene vapors are passed up through a cast-iron tower containing quartz stones, through which hot sulphuric acid is descending. Much less sulphuric acid is required and isomeric changes are largely prevented as the reaction product is rapidly removed from the reaction chamber. Another advantage is that the process is continuous. Experiments were conducted at temperatures varying between 220° and 245° C. Sulphuric acid of 80 to 95 per cent. strength was employed. The reaction product consists essentially of naphthalene—2, 7—disulphonic acid, with some naphthalene—2, 6—disulphonic acid and traces of naphthalene-monosulphonic acid. Analyses show that 78 to 85 per cent. of the disulphonic acids produced by this method is naphthalene—2, 7—disulphonic acid.

* Communicated by the Chief of the Bureau.

[1] Published in *J. Ind. Eng. Chem.*, **16** (Dec., 1924) : 1252.

[2] Published in *J. Ind. Eng. Chem.*, **16** (Dec., 1924) : 1264.

THE TRYPTOPHANE AND CYSTINE CONTENT OF VARIOUS PROTEINS.[3]

By D. Breese Jones, C. E. F. Gersdorff, and O. Moeller.

[ABSTRACT.]

THE cystine and tryptophane contents of a large number of proteins from many different foodstuffs have been estimated colorimetrically in the Bureau of Chemistry. Cystine was estimated by the method of Folin and Looney and tryptophane by May and Rose's method, with certain modifications. Marked differences were found to exist between the various alcohol-soluble proteins (prolamins). As a class, the prolamins are low in tryptophane and rather high in cystine. Zein from corn and the prolamins from oats, sorghum, and teosinte are entirely lacking in tryptophane. The cystine content of oat prolamin (3.48 per cent.) exceeds that of most, if not all, other plant proteins. The proteins of wheat bran were high in these amino acids, the albumin containing 4.76 per cent. and the globulin 2.85 per cent. of tryptophane, and the cystine content was 3.29 per cent. and 1.52 per cent., respectively. The globulin of the almond differs from that of the English walnut, filbert, Brazil nut, and cocoanut by being lower in tryptophane and in cystine. Rye gliadin is lower in tryptophane and higher in cystine than wheat gliadin. Lactalbumin was found to contain about 4 per cent. of cystine. Tryptophane was entirely lacking in each of three brands of gelatin, and the cystine content ranged from 0.15 to 0.31 per cent. A comparison of the cystine content of thirty proteins, as determined both by the Van Slyke and by the colorimetric methods, shows a close agreement between the results obtained by the two methods.

THE NON-VOLATILE ACIDS OF THE DRIED APRICOT.[4]

By E. K. Nelson.

[ABSTRACT.]

THE Bureau of Chemistry conducted an investigation to determine, by the ester distillation method, what acids are present in dried apricots. It was found that the non-volatile acids of the dried apricot consist of a mixture of *l*-malic acid and citric acid, in the proportion of about 25 to 10, with traces of an unidentified acid which may be oxalic acid.

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[3] Published in *J. Biol. Chem.*, **62** (Nov., 1924) : 183.

[4] Published in *J. Am. Chem. Soc.*, **46** (Nov., 1924) : 2506.

NOTES FROM THE DEPARTMENT OF THE INTERIOR, U. S. BUREAU OF MINES.*

HEALTH HAZARDS IN THE MINING INDUSTRY.

By R. R. Sayers.

Some mine dusts, notably those from lead, mercury, zinc and arsenic ores, are poisonous when they come in contact with the human body. The more soluble dusts from these ores are the more dangerous. As an example, men are often badly poisoned when mining carbonate or oxide ores of lead, whereas lead poisoning is rare among men mining only galena, or lead sulphide. Another example is the mining and smelting of mercury, where the hazard has long been recognized. When the ore contains free mercury or the more soluble salts, and when the workings are underground and poorly ventilated, some cases of poisoning occur, but the number is far greater among the employees about reduction plants. Poisonous dusts are rarely, if ever, found in coal mines. The preventive treatment in such cases is much more important than the curative treatment.

Some dusts, when breathed, irritate the lungs and produce a disease known by the general name of "pneumoconiosis." This lung disease is called "silicosis" when it is due to breathing rock dust, especially fine silica; "anthracosis," when due to breathing coal dust, and "siderosis" when due to breathing iron dust. Anthracosis is sometimes called coal miners' phthisis or coal miners' asthma. In addition, the breathing of dust sometimes results in or predisposes to bronchitis and other respiratory diseases.

The principal health hazards in the coal mines of the United States are due to abnormal conditions of the air, as the presence of carbon monoxide, hydrogen sulphide, and increased carbon dioxide, oxygen deficiency, high temperatures and humidities, and possible hazards due to breathing dusts.

The hazards due to impure drinking water and methods for obtaining safe drinking water, and safe methods of sewage disposal in mines have also been studied.

Miners' nystagmus has not been reported in this country and

* Communicated by the Director.

probably does not exist, due to the better illumination found in American coal mines.

Beat knee, beat hand, and beat elbow are important hazards in the mines of Great Britain, but cannot be considered so, excepting in very limited areas, in the United States. A more detailed account of the investigation will be found in Serial 2660, recently issued by the Bureau of Mines.

EXPLOSIVES USED IN MINING.

By W. W. Adams.

THE quantity of explosives consumed in the United States in October, 1924, according to manufacturers' reports to the Bureau of Mines of the Department of the Interior, amounted to 653,694 kegs of twenty-five pounds each of black blasting powder, 5,319,912 pounds of "permissible" explosives, and 23,031,157 pounds of other types of high explosives. A comparison of the figures with those for October, 1923, based on returns from identical companies, indicates a slight increase for permissibles and other high explosives and a slight reduction in the consumption of black powder. The decrease in the sales of black powder was due mainly to inactivity in the coal-mining industry which is the chief consumer of black powder. Of the total sales of all classes of explosives in October, the coal and metal mines of the country used about 68 per cent. Tabulated statistics on explosives consumption will be found in Serial 2659 of the bureau.

POLLUTION BY OIL OF THE COAST WATERS OF THE UNITED STATES.

By F. W. Lane.

THE rapid expansion of the petroleum industry, the steadily growing use of oil fuel for steamships, the increasing transportation of oil in tankers, and the extensive use of petroleum oils for many land industries, has resulted in pollution of our coastal waters by these oils.

On account of the great importance of this problem to the petroleum and shipping industries, the Bureau of Mines, in coöperation with the American Petroleum Institute and the American Steamship Owners Association, has undertaken to ascertain the extent of petroleum oil pollution along the coasts of the

United States, and to indicate the principal sources of such pollution. Certain typical methods and devices in use and proposed for the separation of oil from water, and for the disposal of oily wastes from ships and industrial plants, have been studied. An attempt has also been made to point out the nature of the fire hazard resulting from oil pollution and to indicate the effect of such pollution on bathing beaches.

With the aid of duly qualified government authorities, the effect of coastal oil contamination on marine and wild life has been outlined and its effects upon the public health have been briefly dealt with. Finally, a study has been made of typical oil-burning vessels, in order to visualize the conditions prevailing in marine practice and to aid in an appreciation of the difficulties and problems involved in the operation of such vessels. A fuller account of the results of this investigation is contained in Serial 2658, now available.

EXHAUST GASES FROM ENGINES USING ETHYL GASOLINE.

By R. R. Sayers and A. C. Fieldner.

ONE of the outstanding problems confronting automotive engineers in attempting to construct motors of greater economy is that of eliminating the "knock" from the operation of the engine. Recent investigations of this detonation or knock in internal-combustion engines, especially of the high-compression type, have demonstrated that it can be eliminated or reduced by decreasing the reaction velocity of combustion by adding small quantities of certain compounds to the gasoline. This makes it possible to use engines of a higher compression ratio, thereby greatly increasing the mileage per gallon of gasoline consumed. The savings in fuel reserves from increasing the proportion of crude oil marketable as motor fuel and in permitting the designing of more efficient engines are obvious.

Ethyl gasoline, one of the widely used anti-knock fuels, is ordinary motor gasoline to which has been added 3 c.c. of tetraethyl lead and 2 c.c. of a halogen carrier, as ethylene dibromide or trichlorethylene, or approximately 0.04 per cent. of the lead compound and 0.06 per cent. of ethylene dibromide by volume. Ethyl gasoline should not be confused with ethyl fluid, which is a mixture of concentrated tetraethyl lead and ethylene dibromide in the proper proportions for mixing with gasoline, but is not a

motor fuel and is not sold to the public. Also tetraethyl lead is not a motor fuel, and likewise is not sold to the public.

The Bureau of Mines, in coöperation with the General Motors Research Corporation (later the General Motors Chemical Co.), is conducting an investigation to determine whether any public health hazards, especially lead poisoning, will result from the use of ethyl gasoline. The laboratory work is conducted at the Pittsburgh experiment station of the bureau under the direct supervision of its technical staff, and the bureau has reserved the privilege of publishing the results of the work, favorable and unfavorable.

The purpose of the investigation is to determine whether there is any additional hazard to health (1) in breathing air which contains appreciable concentrations of exhaust gases from engines using ethyl gasoline and (2) in handling and using the raw ethyl gasoline, that is, by inhalation of the vapors or by absorption through the skin. The second phase of this work has only recently been started, and enough data have not been obtained from which to draw conclusions.

Experiments have been completed on exhaust gases from engines using ethyl gasoline as commercially sold. Various types of animals were exposed for certain periods of each day to a definite concentration of exhaust gas from an engine using ethyl gasoline. These exposures were made to simulate the worst conditions, as to time of exposure and concentration of gas in the air, to which people could be exposed without being poisoned by the carbon monoxide in the exhaust gases. The tests were continued over a period of eight months, in order to bring out cumulative effects. Animals of several species, sizes, and ages were used to take care of a possible tolerance or susceptibility. Study of an additional phase, using an increased quantity of ethyl fluid in gasoline, is in progress.

The apparatus used consisted of a 1000-cu. ft. gas-tight chamber, having an anteroom or air lock for entering and leaving during the course of the test without causing changes in or escape of the gas. During the period from December 6, 1923, to April 5, 1924, the chamber was ventilated by air entering through several small pipes near the bottom of the chamber and exhausted near the top of the chamber. From April 5, 1924, to July 27, 1924, the air ventilating the chamber entered near the ceiling of the cham-

ber and, after a general circulation through the chamber, passed out through a duct which opened near the floor. The quantity of air circulated was that which was found necessary for diluting the exhaust gases to the test conditions. The average amount of air going through the chamber was approximately 30,000 cubic feet per hour, or sufficient to make one complete air change every two minutes.

With the exception of animals dying from causes ascertained to be other than lead, all remained normal as to activity, growth, appetite, and general signs of health. Those that died had normal appetites and were active up to within a couple days before death, which is not in accordance with lead poisoning.

This non-occurrence of lead poisoning is further substantiated by the small quantity of lead present in the exhaust gas-air mixture, together with observations on men that 75 per cent. or more of the lead coming from the exhaust is again exhaled when inhaled, leaving the remainder of less than 25 per cent. to be absorbed from the lungs and swallowed, a part of which will be further eliminated in body excretions and expectoration.

The only danger of lead poisoning to the public from products of combustion from ethyl gasoline seems to be confined possibly to the mechanic who is continually cleaning carbon from motors. Although this is but a possibility, it merits precaution, although the occupation would appear to be no more hazardous than painting, lead being the common base of paints.

In summing up, there has been no indication of plumbism in any of the animals used, though they were exposed for 188 days during a period of approximately eight months to exhaust gases from ethyl gasoline in concentrations with respect to lead content that are several times that allowable from the standpoint of carbon monoxide. Additional details are presented in Serial 2655, just published by the Bureau of Mines.

New High-power Locomotive.—The status of steam railroad transportation may be very much modified by the introduction of a new type of locomotive stated to be capable of developing one-third more power with one-third less consumption of fuel and water. This engine was installed by the Delaware and Hudson Company. A trial trip was taken on a special train with a large number of guests, running from Albany to Colonio. The new locomotive has been named "Horatio Allen." Mr. L. F. Loree, President of the

road, drew a vivid picture of the comparison between transportation conditions in the year 1828 when the company obtained four locomotives from England and the present day. Horatio Allen, then a young man, was agent in the matter of obtaining the engines. One of these was set up at Honesdale, Pennsylvania, on August 8, 1829. It weighed seven tons, cost $2900, and was capable of hauling a train load of ten tons on level track at four miles an hour. This was the first locomotive to operate on the western hemisphere. The new engine weighs two hundred and seventy-three tons and cost $105,000. In explaining the principal features of the new engine, President Loree stated that it requires comparatively little additional heat to put steam under pressure. To raise steam to three hundred and fifty pounds pressure and thus secure 75 per cent. more power requires a very small amount of heat units. It is this high pressure which would be carried by the new locomotive. In the construction of the engine, the parts bearing the pressure have been carefully strengthened and the locomotive has a higher factor of safety than is ordinarily adopted.

In engineering circles such advances in the construction of the steam locomotive are attracting a great deal of attention because of their possible influence on the theory of superpower systems. A fundamental competition exists between systems of transportation in which the trains are operated from central units and those in which each train is drawn by its own power unit. The construction, therefore, of this new locomotive is an important step in this competition, and its performance will certainly be watched with a great deal of interest by transportation engineers. H. L.

"IN MORE recent times, overwhelming evidence has accumulated which makes it impossible to doubt the existence of a real contact difference of potential between two metals of a much greater order of magnitude than the Peltier effect. It is demanded by the theory of electron emission from metals; it has been experimentally demonstrated in a particularly conclusive and elegant manner by Millikan and his co-workers." (J. A. V. BUTLER, *Phil. Mag.*, Oct., 1924, p. 747.) G. F. S.

THE FRANKLIN INSTITUTE.

(Proceedings of the Annual Meeting held Wednesday, January 21, 1925.)

HALL OF THE FRANKLIN INSTITUTE,

PHILADELPHIA, January 21, 1925.

DR. WM. C. L. EGLIN, President, *in the Chair.*

Additions to membership since last report, 7.

On motion duly seconded the resolution of the Board of Managers recommending the election to Honorary Membership of the Hon. William Cameron Sproul, Ex-Governor of the State of Pennsylvania, was unanimously adopted.

The President then presented his Annual Report of the activities of the Institute during the year ending September 30, 1924, and referred briefly to the operations of the several Standing Committees and the Bartol Research Foundation.*

The Secretary read the report of the tellers of the election, Doctors Leffmann and Stine. The following gentlemen were declared duly elected to the following offices:

Wm. C. L. Eglin, President, to serve one year; Henry Howson, Vice-president, to serve three years; Benjamin Franklin, Treasurer, to serve one year; Managers to serve three years: Francis T. Chambers, Alfred C. Harrison, Nathan Hayward, Charles A. Hexamer, Robert W. Lesley, Marshall S. Morgan, E. H. Sanborn, J. T. Wallis.

The Chairman then introduced Mr. W. N. Jennings, a member of the Institute, who addressed the meeting on "Rapid-Fire Photography." Mr. Jennings described the numerous journeys which he has taken to various parts of the world for the purpose of obtaining photographs illustrating special features of the countries and their inhabitants. He also gave an account of his airplane journeys for the purpose of taking bird's-eye-view pictures of industrial establishments, estates, etc., and described his hasty trip by airplane to Lakehurst, N. J., for the purpose of photographing the ZR-3 (*Los Angeles*) on its arrival in this country. The subject was illustrated by more than one hundred lantern slides from original photographs.

A rising vote of thanks was extended to the speaker and the meeting adjourned.

GEORGE A. HOADLEY,
Acting Secretary.

* This report and the reports of the several Standing Committees will appear in the next issue of the Year Book of the Institute.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, January 7, 1925.)

HALL OF THE INSTITUTE,
PHILADELPHIA, January 7, 1925.

The following report was presented for final action:

Revision of Regulations of Science and Arts Committee.

The following reports were presented for first reading:

No. 2745: Hoke Method of Making Precision Gauge Blocks.

No. 2827: Long Life Molds.

No. 2831: Literature.

No. 2832 and No. 2833: The Franklin Medal.

The following preambles and resolutions were adopted:

In the death of Edward V. McCaffrey, the Committee on Science and the Arts of The Franklin Institute has lost a staunch friend and a member who has for years rendered an unstinted service. Joining the Institute in 1910 as a natural result of his graduation from its School, he became a member of the Committee on Science and the Arts in 1912 and since that time has served on many of its Sub-committees.

Mr. McCaffrey was for several years a valued member of the Institute's Committee on Instruction in which his familiarity with the needs of the school was of distinct value to the Committee.

Therefore, be it *Resolved*, That the Committee on Science and the Arts hereby records its regret at the death of Mr. Edward V. McCaffrey and expresses its sympathy with his family in their loss.

And be it *Further Resolved*, That this report be spread upon the Minutes of the Committee on Science and the Arts and that a copy be sent to Mr. McCaffrey's family.

The Committee on Science and the Arts of The Franklin Institute, sensible of the loss which its membership has sustained through the untimely death of Roger F. Brunel on December 23, 1924, unanimously

Resolves, That there be recorded in its Minutes an appreciation of the faithful service rendered by him as a member of this body during the past three years and a recognition of his personal charm as a collaborator and his sterling qualities as a scientist.

And the Committee *Further Resolves*, That these resolutions be spread upon the Minutes of the Committee on Science and the Arts, be printed in the JOURNAL OF THE INSTITUTE and a copy thereof be transmitted to the family of the deceased.

GEORGE A. HOADLEY,
Acting Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, January 14, 1925.)

RESIDENT MEMBERS.

DR. HORACE C. RICHARDS, Professor of Mathematical Physics, 4812 Fairmount Avenue, Philadelphia, Penna.

MR. GERALD E. SCANNELL, Experimental Machinist, 3123 Tulip Street, Philadelphia, Penna.

MR. A. S. WOODLE, JR., Engineer, Ridley Park, Penna.

NON-RESIDENT MEMBERS.

DR. ELMER K. BOLTON, Chemist, Jackson Laboratory, Box 525, Wilmington, Del.

MR. FRANK L. DYER, Mechanical Expert, 217 Broadway, New York City, N. Y.

DR. SAMUEL E. POND, Teacher, Medical School, Scott and Euclid Avenues, St. Louis, Mo.

ASSOCIATE MEMBERS.

MR. ARTHUR H. ALLEN, JR., Inventor, 4019 Baring Street, Philadelphia, Penna.

CHANGES OF ADDRESS.

MR. CARL G. BARTH, 424 Whitney Avenue, New Haven, Conn.

MR. CHRISTO CASACOF, Apartado 12181, Madrid, Spain.

PROF. G. LANZA, 5624 Cedar Avenue, Philadelphia, Penna.

MR. KARL F. OERLEIN, 2943 Cambridge Street, Philadelphia, Penna.

MR. HENRY J. STEUBER, 113 Essex Avenue, Montclair, N. J.

MR. C. H. UMSTEAD, Post Office Building, Cambridge, Mass.

MR. F. E. WHITNEY, 6653 Lawnton Avenue, Philadelphia, Penna.

MR. EDWARD L. ZIESEL, 3350 North 15th Street, Philadelphia, Penna.

NECROLOGY.

John C. Trautwine, Jr., whose death occurred on July 4, 1924, was a native Philadelphian who received his education in the public schools of the city. In his early manhood he assisted his father in revising, editing and extending the scope of the "Civil Engineer's Pocket Book," the first edition of which was published in 1872 and which made the name Trautwine familiar to engineers. He early became interested in hydraulics and translated several books on the subject.

He was for twelve years Secretary of the Association of Engineering Societies and Editor of its Journal. He held, for four years, the position of Chief Engineer of the Bureau of Water for Philadelphia and frequently served the city by examining candidates for municipal engineering positions.

He had an extended practice as a consulting engineer for which his intimate knowledge of the principles of engineering and his practical experience in the applications of these principles furnished an adequate preparation.

He was a Life member of The Franklin Institute, having joined on October 28, 1874.

Mr. William Sartain, whose membership possibly antedated that of any other member of The Franklin Institute, died in New York on October 25, 1924.

Mr. Sartain became a Life member of the Institute in 1859 and always maintained a lively interest in its work. His interest in the results of modern scientific research is shown in a letter sent to the Institute in 1923, in which he refers to a poetical allusion in Lucretius' "De Natura Rerum," which might possibly be considered an anticipation of ultra-violet and heat radiation.

Mr. Walter F. Ballinger, 12th and Chestnut Streets, Philadelphia, Penna.

Dr. Roger F. Brunel, Department of Chemistry, Bryn Mawr College, Bryn Mawr, Penna.

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BOOK REVIEWS.

PHYSIKALISCHES HANDWÖRTERBUCH. By Arnold Berliner and Karl Scheel. vi–903 pages, with 573 illustrations, large 8vo. Berlin, Julius Springer, 1924. Price, $9.30.

"Handbuch" is a not infrequent designation of German textbooks, and sometimes the term is rather ironical. The present volume is more conveniently consulted by laying on the table than by holding it in the hand. It is, however, a vast collection of data in the departments of both pure and applied physics, a

science which has grown by leaps and bounds within the last twenty years or so, and threatens now to absorb both chemistry and astronomy in its borders. The work is dedicated to Walther Nernst, fully worthy of the honor. In the preface the authors quote Lessing to the effect that a preface should be limited to a history of the work. Notwithstanding Lessing's eminence as a dramatist and critic, the reviewer does not consider this doctrine as entirely sound. A book without a preface would indeed be somewhat like a dinner without a dessert, and though the comparison may seem to be upside down, as the preface precedes while the dessert follows the substance, yet it is well known to authors, printers and reviewers that the preface is generally written last. It affords the author an opportunity to review his work, bid a farewell for the time being to his readers, and to point out the commendable features, or even to apologize for shortcomings.

This work grew out of the necessity of obtaining quick information upon many points in physics, and was especially developed among certain members of the German Physical Society. To search through monographs, reprints and similar scattered materials is tedious and difficult. The book was planned during the war. The authors declare that they accept Lessing's dictum, yet they discuss in the preface some features of the work which are not parts of its history.

Of the main text of the book only praise can be said. Every phase of pure and applied physics is covered, illustrations are freely used and the type is clear and distinct. The dictionary method is strictly followed, by which, of course, cognate subjects are usually widely separated. It is a question whether this form is as satisfactory as a strictly systematic arrangement with a good index. For a dictionary proper, that is, a series of definitions with pronunciation and etymology, of course the alphabetical arrangement is necessary, but books of the type of the one now in hand are much more than dictionaries, although they may be called so or by the title "Wörterbuch." They are descriptive manuals, and the systematized form is possibly the best. The book includes much modern chemistry, and the teacher of chemistry will find a great deal that will be very useful.

The examination of works on physical and chemical science printed in the languages of continental Europe, especially in France and Germany, furnishes some unpleasant observations. There seems to be a greater tendency than in former years away from uniformity of nomenclature. The French chemists use superiors for the exponents of atoms, and a great many of them still use Az for nitrogen. In a recent article on tungsten compounds, in a French pharmaceutic journal the symbol for this metal was given Tu, a wholly improper form. The author probably was so nationalistic in his science that he was unwilling to use the abbreviation of the German name, which is the standard symbol. In the book in hand it is noted that the Ångström unit, of which the generally accepted form is AU, is written A°E, the last letter being presumably the abbreviation of "Einheit." If the circle is to be used at all it should be over the A and not after it. It would seem, however, that inasmuch as the word "unit" comes from the Latin, the German physicists might retain the symbol as uniform with French and English custom.

A closing paragraph of the preface reads:

"Taken all in all, merits and defects of the book, we may say the merits lie in the things set forth, the defects in the things omitted. The issuers do not deserve approval for the merits, nor disapproval for the shortcomings. They can, therefore, send the book out with a clear conscience and with the maxim of Logau,

> "Go forth to all the world, my book, withstand what haps,
> Some may bite, some may tear, but may they not harm me."

The authors of the book might have found in English a better blessing in Southey's lines:

> "Go, little book, from this my solitude,
> I cast thee on the waters, go thy ways,
> And if, as I believe, thy vein be good,
> The world will find thee after many days."

Certainly, the work is a most valuable addition to the literature of modern physics and shows well the importance of a good reading knowledge of the German language to English-speaking scientists, since many phases of physics and physical chemistry are clearly and elaborately set forth in its pages. The mechanical execution is excellent.

HENRY LEFFMANN.

A SYSTEMATIC HANDBOOK OF VOLUMETRIC ANALYSIS. By Francis Sutton, F.I.C., F.C.S. Eleventh edition, revised throughout by W. Lincolne Sutton, F.I.C., and Alfred E. Johnson, B.S., F.I.C. xii–624 pages, index and numerous illustrations, 8vo. Philadelphia, P. Blakiston's Son and Company, 1924. Price, $9.

The first edition of this work dates back to 1863. It is, therefore, long past its semi-centennial. The tenth edition appeared in 1911, when the author was in his eightieth year, but was able to sign the preface. Little need be said about the book for it has long been a dominant reference work in the laboratory. The convenience and brevity of volumetric processes have led to their extensive adoption and to constant efforts to extend their applicability and accuracy. The field was comparatively new when Sutton offered his manual, but even then it was a book of good size. Sutton felt that it was the least perishable work of his life and it has proved so. The work has been out of print for several years, partly on account of the interference of the war, and is now issued in a completely made-over form. A good change is the printing of the procedures in full-sized type, instead of the small type used for such portions in former editions.

The preface gives details of many parts that have been re-written. Among these are the sections on indicators, full details of the methods of standardization in the National Physical Laboratory, tannins, water and sewage analysis, gas analysis. Considerable portions of the book are contributions by collaborators, a method now necessary in all fields of applied science. The result of the work of the editors and their associates is a book that is indispensable to the analyst in all departments. The mechanical execution is excellent.

HENRY LEFFMANN.

MATERIA PHOTOGRAPHICA. A Dictionary of the Chemicals, Raw Materials, Developing Agents and Dyes Used in Photography. By Alfred B. Hitchins, Ph.D. 95 pages, 18mo. Philadelphia, Frank V. Chambers, 1924. Price, $1.

"Materia medica" has long been a familiar term, and Doctor Hitchins has aptly coined a suitable word for the materials covered by his book. It contains a large amount of information clearly and conveniently expressed. An important point in its usefulness is its missionary value in promoting among photographers a knowledge of correct forms of chemical nomenclature. It will help to eradicate such monstrosities as "bromide of potash" and "soda hyposulphite." The book is in the excellent style as to typography and presswork that characterizes the offerings of the Chambers Press and is a welcome addition to current photographic literature.

Query. Why not an American Photographic Annual from the Chambers Press?

HENRY LEFFMANN.

THE PHYSICS OF THE DEVELOPED PHOTOGRAPHIC IMAGE. By F. E. Ross. 294 pages, bibliography, index and eighty-two illustrations. Small 8vo. Eastman Kodak Company, by D. Van Nostrand Company, New York, 1924.

This is No. 5 of the series of "Monographs on the Theory of Photography" in course of publication by the Research Laboratory of the Eastman Kodak Company. A captious critic might object that the line of work recorded in these essays is largely the facts of photographic phenomena, rather than the theory thereof, but the merit of the publications is unquestionable, and the E.K.C. deserves the thanks of physicists and physical chemists for its energy in pursuing the investigations, for its liberality in financing them and its frankness in giving the results to the public.

Each volume of the series is by a different author, recording the results of his studies, but the series is under general charge of Doctor Mees and Miss Garvin. The subject-matter of the present volume is an important feature of photographic procedure. The studies are limited mainly to the physical side of the phenomena, and to the emulsions of silver halides. This phase is, of course, the important one in modern photography, but it seems that interesting and useful lines are open in the study of the physics and chemistry of other photosensitive substances.

In an essay on development, the question of the latent image cannot be kept out. The subject is briefly mentioned in several places, one of the most striking statements being a quotation from Scheffer's article in the *British Journal of Photography* to the effect that the developed grain of the silver halide is not exactly coincident with the grain on which the light impression is made, that is, there is a displacement of the latent image in development. The same view is given in a quotation from Piper, who states definitely that the latent image is in itself undevelopable. From this view Piper reasons out a theory of the reversal of the image by long exposure. In this connection the work of Nipher on the progressive reversal of the image might be worth reëxamination by means of the excellent microscopic apparatus in possession of the E.K.C. A study of the conditions of the gelatin after pre-development fixation is also advisable.

HENRY LEFFMANN.

PUBLICATIONS RECEIVED.

Switchgear for Electric Power Control, by E. Basil Wedmore and Henry Trenchham. 335 pages, illustrations, 8vo. Oxford University Press, 1924. Price, $8.35.

Kelvin Centenary Oration and Addresses Commemorative. 100 pages, portrait, 8vo. London, Percy Lund Humphries and Company, Ltd., 1924. Price, six shillings net.

Popular Science Talks. A series of popular lectures on eleven interesting topics. 239 pages, illustrations, 8vo. Philadelphia College of Pharmacy and Science, 1925. Price, $1.

Einstein's Theory of Relativity, by Max Born, translated by Henry L. Brose. 293 pages, illustrations, 8vo. New York, E. P. Dutton and Company. Price, $5.

Sources of Volcanic Energy, by John C. Soley, U. S. N. 247 pages, illustrations, plates, maps, 8vo. New York, G. P. Putnam's Sons, 1924.

Technical Mechanics: Statics, Kinematics, Kinetics, by Edward R. Maurer and Raymond J. Roark. Fifth edition, rewritten. 364 pages, illustrations, 8vo. New York, John Wiley and Sons, Inc., 1925. Price, $3.50.

Cugle's Practical Navigation, by Charles H. Cugle. A new and complete work on navigation which explains thoroughly the changes in the Nautical Almanac for 1925. 351 pages, plates, 8vo. New York, E. P. Dutton and Company, 1924. Price, $6.

Factory Practice in Manufacture of Azo Dyes, by W. B. O'Brien. 176 pages, illustrations, 8vo. Easton, Penna., The Chemical Publishing Company, 1924. Price, $5.

Combustion in the Power Plant. A coal burner's manual, by Thomas A. Marsh. 255 pages, 12mo. New York, D. Van Nostrand Company, 1924. Price, $2.

The Physics of the Developed Photographic Image, by F. E. Ross. 217 pages, illustrations, 8vo. New York, D. Van Nostrand Company, 1924.

Melanges de Mathématiques et de Physique, par Emile Picard. Paris, Gauthier-Villars et Cie., 1924. Price, twenty-five Francs.

Leçons sur la Composition et les Fonctions Permutables, par Vito Volterra et Joseph Péres. 183 pages, illustrations, 8vo. Paris, Gauthier-Villars et Cie., 1924. Price, twenty Francs.

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Entropie des Wasserdampfes in elementarer Ableitung, von Fritz Bürk. 47 pages, illustrations, 12mo. Leipzig, Otto Spamer, 1924. Price, two marks.

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tion Engines under Approximate Altitude Conditions, by R. N. DuBois. 7 pages, diagrams, quarto. Washington, Committee, 1924.

U. S. Coast and Geodetic Survey. Results of Observations Made at the Magnetic Observatory at Sitka, Alaska, in 1921 and 1922, by Daniel L. Hazard. 100 pages, diagrams, 8vo. Results of Observations Made at the Magnetic Observatory Near Honolulu, Hawaii, in 1921 and 1922, by Daniel L. Hazard. 100 pages, diagrams, 8vo. Washington, Government Printing Office, 1924.

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